Agriculture's Role in Protecting Ground Water

CONSERVATION GEM PROGRAM MANUAL

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(listed alphabetically)

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Agriculture's Role in Protecting Groundwater

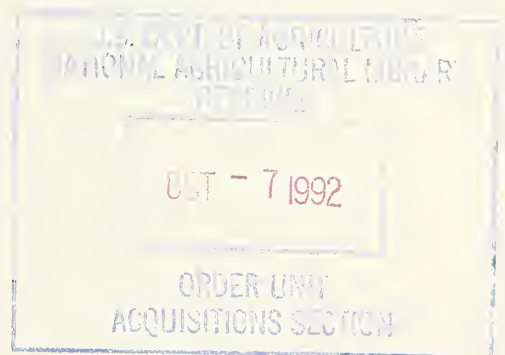# CONSERVATION GEM
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December 1991

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GROUNDWATER
EDUCATION
IN
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I. INTRODUCTION

Ground water is the water below the land surface that completely fills (saturates) the pore spaces in the subsurface materials. Ground water is a vital part of rural life. Nearly 95 percent of rural families in the United States rely on ground water as their source of drinking water. In addition, there are many agricultural uses for ground water such as irrigation and livestock watering. Also, it is a critical component of our natural resource base. The quality of life in the rural community depends on an abundant and dependable supply of potable ground water (i.e. suitable for drinking).

The ground water system is poorly understood by most people. Misconceptions are common. For instance, the perception of ground water occurring as underground lakes and streams is <u>not</u> accurate in most circumstances. Misconceptions like this stem largely from our inability to visualize the water held beneath the surface. Other misunderstandings, particularly those related to the effects of our surface activities on ground-water quality, often lead to unintentional serious threats to our ground water resources.

Anyone who has ever seen photographs of the earth taken from space can appreciate why some call our world the water planet. About 70 percent of its surface is covered by water. But more than 97 out of every 100 drops of water on earth are saline and, therefore, not potable (Table 1). The largest storehouses of fresh water on earth are the ice caps and glaciers. But they are not easily accessible sources of drinking water. Ground water is the premier source of readily available fresh water for human consumption. Compared to other fresh water sources, ground water is 25 times more abundant than all the lakes, reservoirs and rivers of the world combined!

The current quality of our ground water resources is generally very good in most locales. In many rural areas it is used and consumed with little or no treatment. Ground water quality is at risk though. Many common urban, industrial, and farm practices are a potential threat to the quality of our ground water .

Given the economic and life-sustaining importance of ground water to rural residents, we must collectively ensure the conservation of its quality and quantity through education and prudent land practices. An appreciation of the benefits of ground water, coupled with an understanding of the basic concepts of water movement throughout the farm environment, will help us realize the link between our actions at the land surface and how they affect our ground water resources.

Table 1. Estimated Distribution of the World's Water Supply

			% of total
Total saline waters		**97.2079 %**	
	Oceans	97.2	
	Saline lakes	0.0079	
			% of total
Total fresh waters		**2.7921**	**fresh water**
	Ice caps and glaciers	2.158	
77.289			
	Ground water*	0.61	21.847
	Lakes and reservoirs	0.015	
0.537			
	Soil moisture	0.008	
0.287			
	Atmosphere	0.001	
0.036			
	Rivers	0.0001	0.004

* to a depth of 13,000 feet

[modified from Heath, 1987 and Fetter, 1988]

II. BASIC HYDROLOGY & GROUND WATER FLOW

Introduction

Hydrology is the study of the movement and interaction of water on the earth surface, below the surface and in the surrounding atmosphere. Surface water includes streams, rivers, ponds, lakes and the oceans. Water below the ground surface that occupies the tiny open spaces within the soil and subsurface materials is called **subsurface water.** Subsurface water has two components, one is soil moisture which is found in unsaturated areas and the second is ground water which is found in the saturated areas. The water in the atmosphere is held as water vapor which may condense as droplets to fall as precipitation. These three areas of water storage are dynamically linked to each other by the continuous movement of water from place to place. This is the concept of the **hydrologic cycle** (Figure 1).

The Hydrologic Cycle

Within the hydrologic cycle, water moves into and out of the three storage areas (surface water, subsurface water, and atmospheric water). The input of water to one area must be accompanied by an output from another. The pathways of water movement within the hydrologic cycle are outlined in Table 2.

Energy

The driving force behind all water moving pathways are the energy differences from point to point throughout the hydrologic cycle. Solar energy is the primary driving force for the water movement pathway between the surface and the atmosphere. As an example, Figure 2 shows vapor being added to the atmosphere by the evaporation of pond water. Water will always move from a point of higher energy toward the point of lower energy along the path of least resistance. Water will move, for instance, from a zone of higher pressure to one of lower pressure, from higher temperature to lower and from a higher elevation to a lower one.

Hydrologic Cycle

Clouds forming

Evaporation off fields

Evaporation off lake

Precipitation

Transpiration

Runoff

Runoff

Lake

Infiltration

Water table
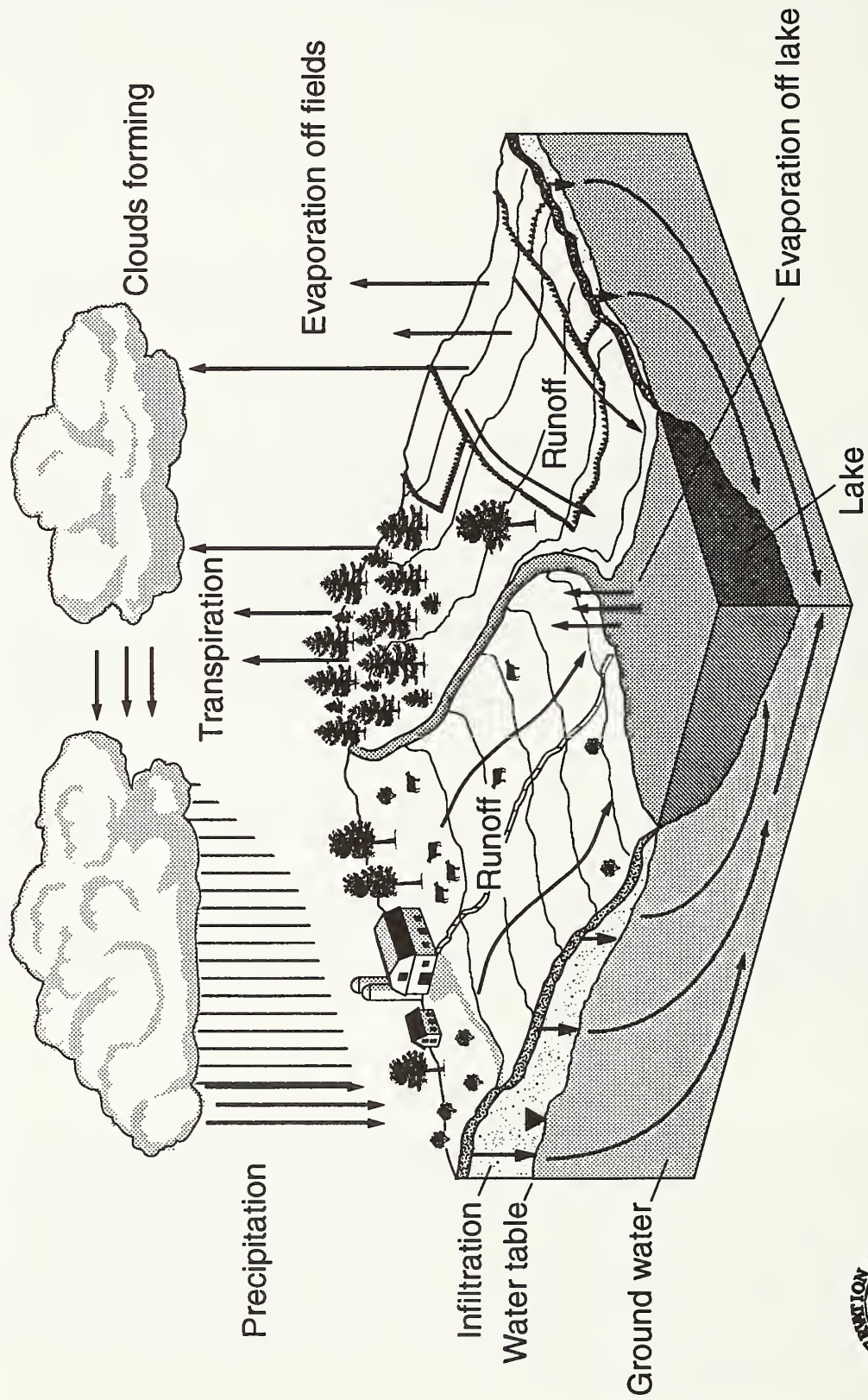
Ground water

Figure - 1

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Table 2. Mechanisms of Water Movement in the Hydrologic Cycle

* Atmosphere to Surface
- precipitation (condensed water vapor)
  [rain, snow, hail, dew, frost]

* Surface to Atmosphere

- evaporation from land or water surfaces
- plant transpiration

* Surface to Surface

- down slope stream flow
- down slope overland flow

* Surface to Ground Water

- ground-surface infiltration and downward movement
- infiltration and downward water movement from loosing streams or ponds

* Ground Water to Surface

- upward ground-water movement into gaining streams or ponds
- root uptake
- artesian water movement producing a flow at the surface from a confined aquifer release point

* Ground Water to Ground Water

- down slope ground water flow within and between aquifers

Energy Sources for Water Movement
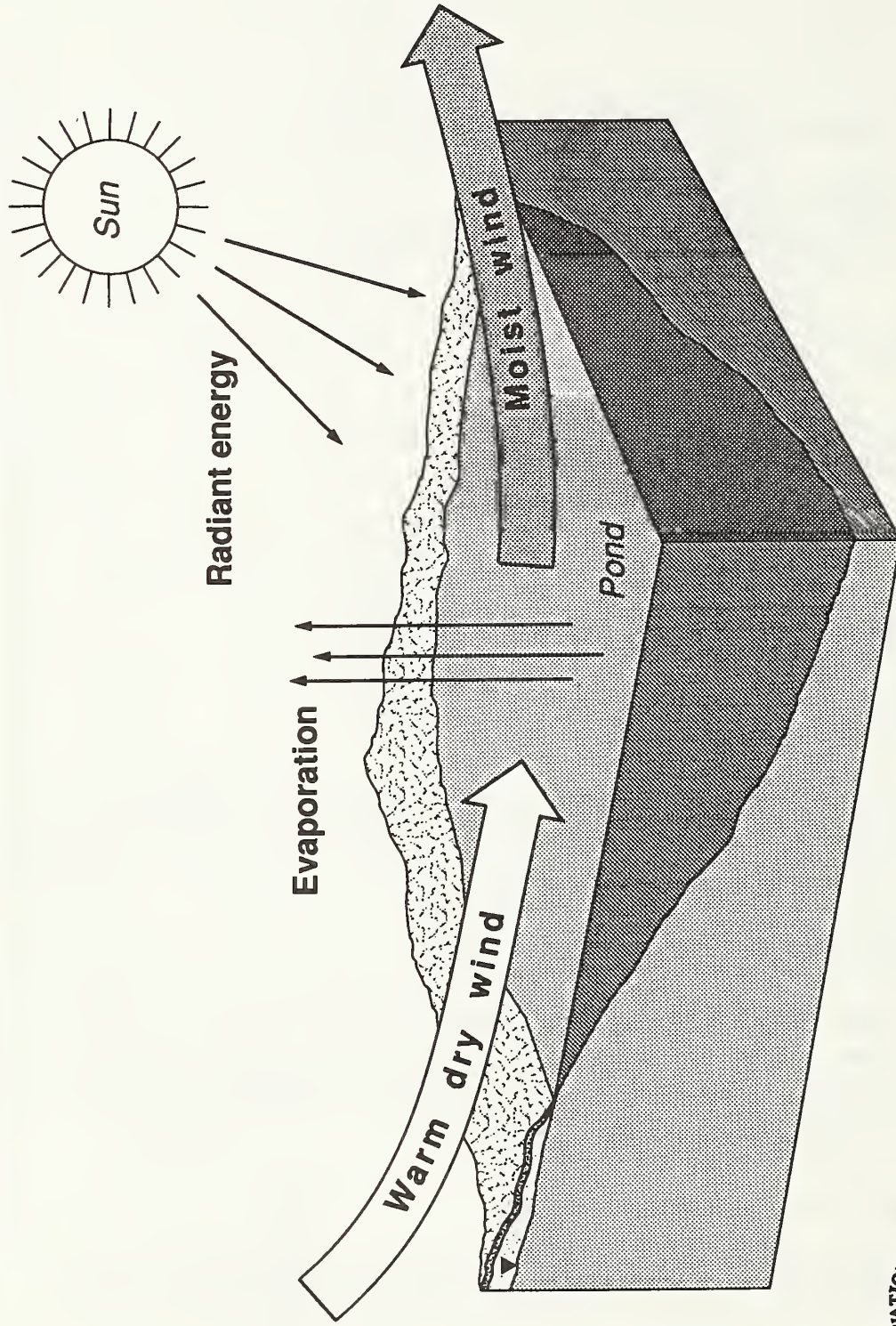
Figure - 2

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The Farm-scale Hydrologic System

Introduction

For the hydrologic discussions throughout this manual the size of land area to be considered will be the farm site and the immediate vicinity around it. This will be considered the **farm-scale hydrologic system**. We will discuss water movement in terms of inputs and outputs through the different areas of water storage in the hydrologic system.

Water Pathways

The farm-scale hydrologic cycle is a description of the cyclical movement of water on and around the farm. Water travels through the cycle by various pathways (Figure 3). The time to completely travel through the hydrologic cycle can vary greatly. Beginning as a raindrop, water can move vertically downward through the soil surface and unsaturated areas as soil moisture and further into saturated areas as ground water. Ground water moves very slowly through the subsurface material. It can creep along, almost horizontally, on a slight grade for years and possibly centuries until it reaches a distant discharge site (Figure 4). On the distant surface, the water can evaporate and finally fall as precipitation again. A much shorter cycle would be precipitation falling onto the ground surface and immediately evaporating. That water could, but usually doesn't, return as precipitation in a few hours.

Water Inputs

Inputs to the farm-scale hydrologic system include all precipitation and irrigation. Rain, dew, snow, sleet, and hail are all forms of precipitation. Irrigation water is applied to the farm-scale hydrologic system from above surface, at the surface and by subsurface methods.

Water Outputs

Outputs from the farm-scale hydrologic system include water movement by surface flow, evaporation from soil and plant surfaces, and infiltration into the subsurface. Surface flow occurs as runoff from snow melt, excess rains or over-irrigation. **Evapotranspiration** is a combination of two water movement pathways, evaporation and transpiration.

Water Pathways

Evaporation and Transpiration

Perennial stream

Orchard

Surface runoff

Row crops

Local ground water flow system

Cover crops

Confined feeding

Infiltration

Water table

Ground water

Regional ground water flow

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Figure - 3

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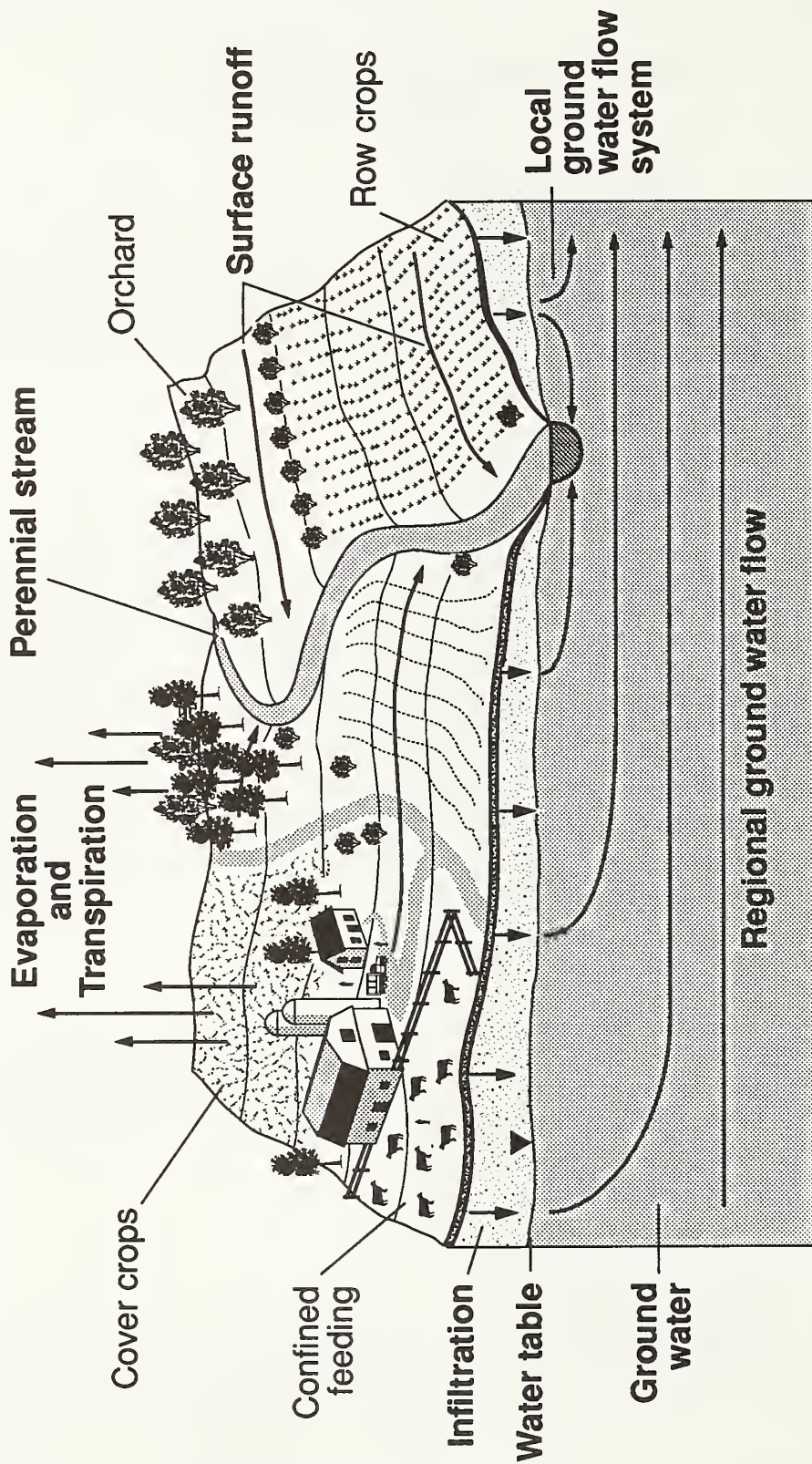
Hydrologic Time Scales

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Figure - 4

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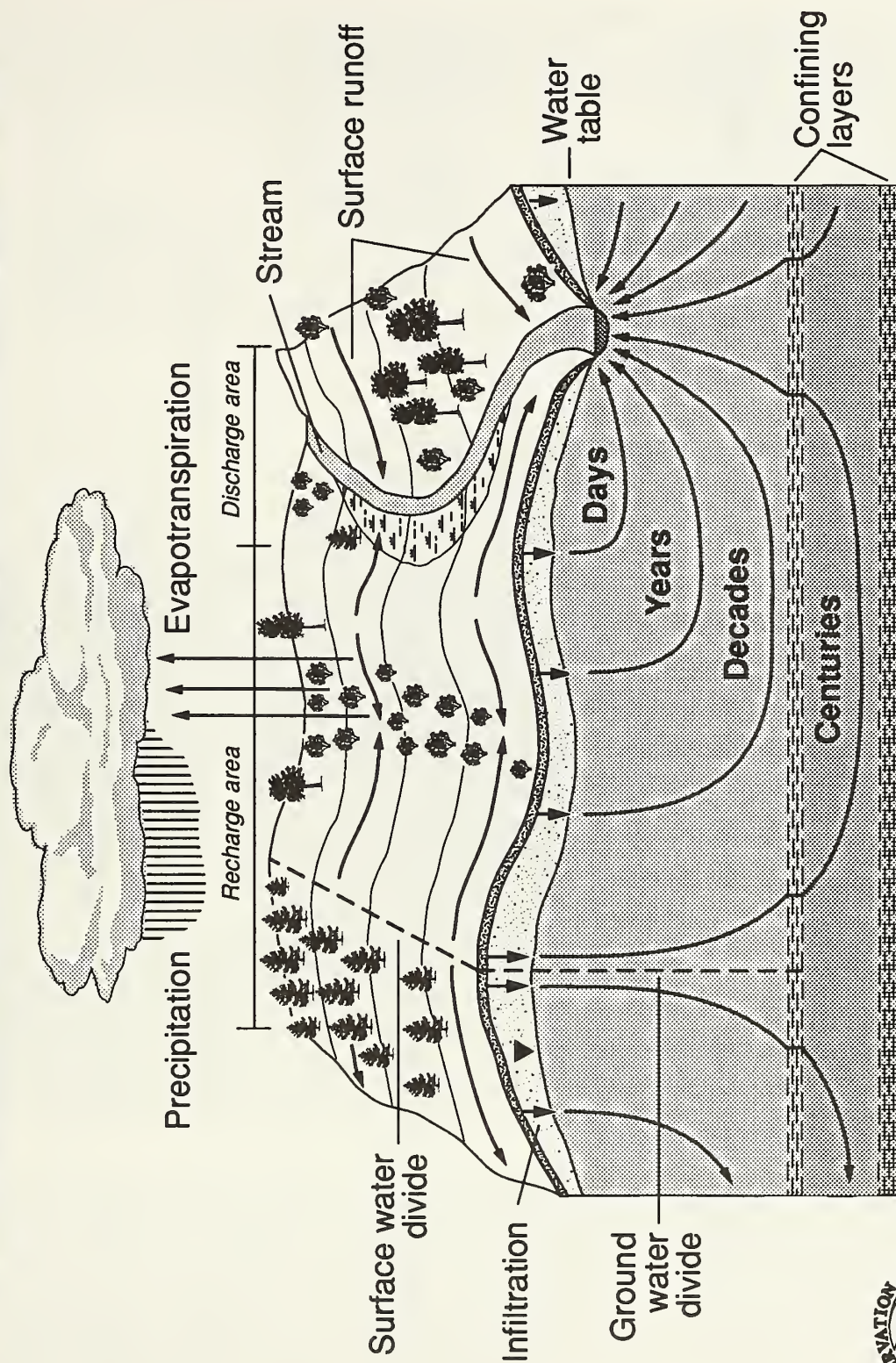
Evaporation is a change of liquid water, from land and water surfaces, to water vapor by energy from the sun and wind. Transpiration is the release of water vapor by plants through their leaves. **Infiltration** is the seepage of water into the ground and **percolation** is the subsequent downward movement of the water, through cracks and pore spaces, into the subsurface.

An additional output is subsurface drainage systems such as tile fields which move water from the subsurface directly to a ditch. Ground water may eventually flow out of the saturated zone directly into a surface water feature such as a stream. This input to perennial streams is called **base flow**. Thus the hydrologic cycle links ground water to surface water, and back again.

The Subsurface

Introduction

We have discussed the major components of the entire farm-scale hydrologic system. Now let's focus on the components of the subsurface and the water movement through this portion of the hydrologic system. The subsurface is divided into two principle regions, the unsaturated zone and the saturated zone (Figure 5). The subsurface materials in these areas can be characterized by their degree of compaction and cementation. From this viewpoint, geologic materials can be classified as 1) unconsolidated, 2) unconsolidated but totally compacted, or 3) consolidated, if compaction and cementation has occurred.

Unsaturated Zone

The **unsaturated zone** is the area of the subsurface that has a combination of air and water within its pore spaces. It contains the **root zone** which is the soil area that plant roots occupy in order to obtain water and nutrients. The unsaturated zone extends from the ground surface down to the **water table** which divides the unsaturated zone from the saturated zone. In other words, the upper surface of the saturated zone is the water table.

The amount of water held in the unsaturated zone is based on the amount of water that soaks into the surface, the amount absorbed by plant roots and the amount that moves downward across the water table into the saturated zone. The unsaturated zone holds water much like a sponge. It can vary from being nearly saturated, with all the soil pores filled, to being wrung out of excess water but still moist. Gravity is responsible for draining the excess water from the unsaturated zone. When the unsaturated zone reaches the point at which no more water can be pulled from it by gravity it is at its **field**

Subsurface Hydrologic Zones

Soil moisture

Air spaces

Soil particles

Ground water

Soil particles

Infiltration

Root zone

Unsaturated zone

Water table

Saturated zone

Figure - 5

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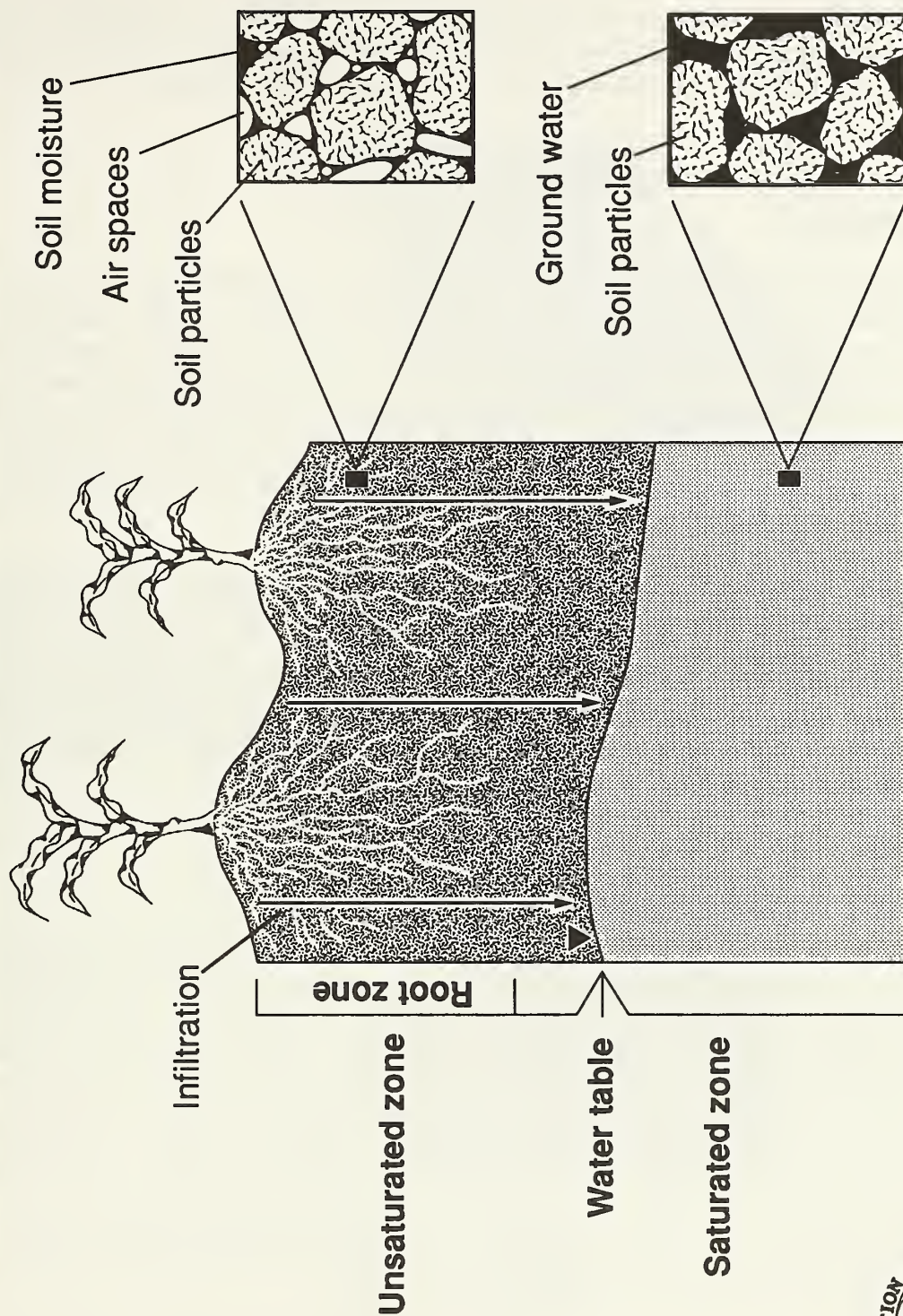
capacity. Before water can infiltrate out of the unsaturated zone into the saturated zone, the water storage capacity (i.e. field capacity) of the soil must be exceeded. This fact provides the irrigation manager with a useful tool to keep expensive water and nutrients in the root zone rather than flushing them through to the water table.

Saturated Zone

The **saturated zone** is the subsurface region where all available voids and pore spaces are completely saturated (i.e. filled) with ground water. This subterranean region can consist of multiple layers composed of soil materials (e.g. clay, sand, or gravel) or various types of consolidated rock. The layers within this zone that can supply ground water of an acceptable quantity and quality are called **aquifers**. Some layers can transmit a great deal of water and some very little, depending on the type of material it is composed of. Sandstone, for instance, can transmit more water than shale and a gravel aquifer can supply water more readily than one of clay material.

Water in the saturated zone, like all other areas of the hydrologic cycle, is moving. It moves much more slowly than water in the other parts of the cycle, but the reason for its movement is the same: an energy difference from higher to lower elevation. Stream flow velocities range from a few feet per minute to a many feet per second. In comparison, ground water moves very slowly. In a coarse sand aquifer, ground-water flow velocities may be as fast as 1 foot per day. A clay layer, on the other hand, may allow ground-water flow at a rate of only 0.3 inches per year!

Unconfined Aquifers

The saturated zone can have two types of productive aquifers within it, unconfined aquifers and confined aquifers (Figure 6). The **unconfined aquifer** is the region which is directly beneath the unsaturated zone with no barrier zones between them. Unconfined aquifers always remain at atmospheric pressure. The water table is the top surface of the unconfined aquifer. The height of the water table will vary with water subtractions from well pumping and water additions from excess infiltration that percolates down through the unsaturated zone and into the aquifer or saturated zone. Unconfined aquifers have a bottom barrier zone that slows downward movement of water and allows the water to build up into the unsaturated zone. With no barrier zone on top of the unconfined aquifer, the vertical movement of the water table from inputs and outputs occurs continually and with no pressure change.

Aquifer Types

Water table

Perennial stream

Line of springs

Perched aquifer

Confining layers

Unconfined aquifer

Confined aquifer

Confined aquifer

Leakage through cracks and breaks in confining layer
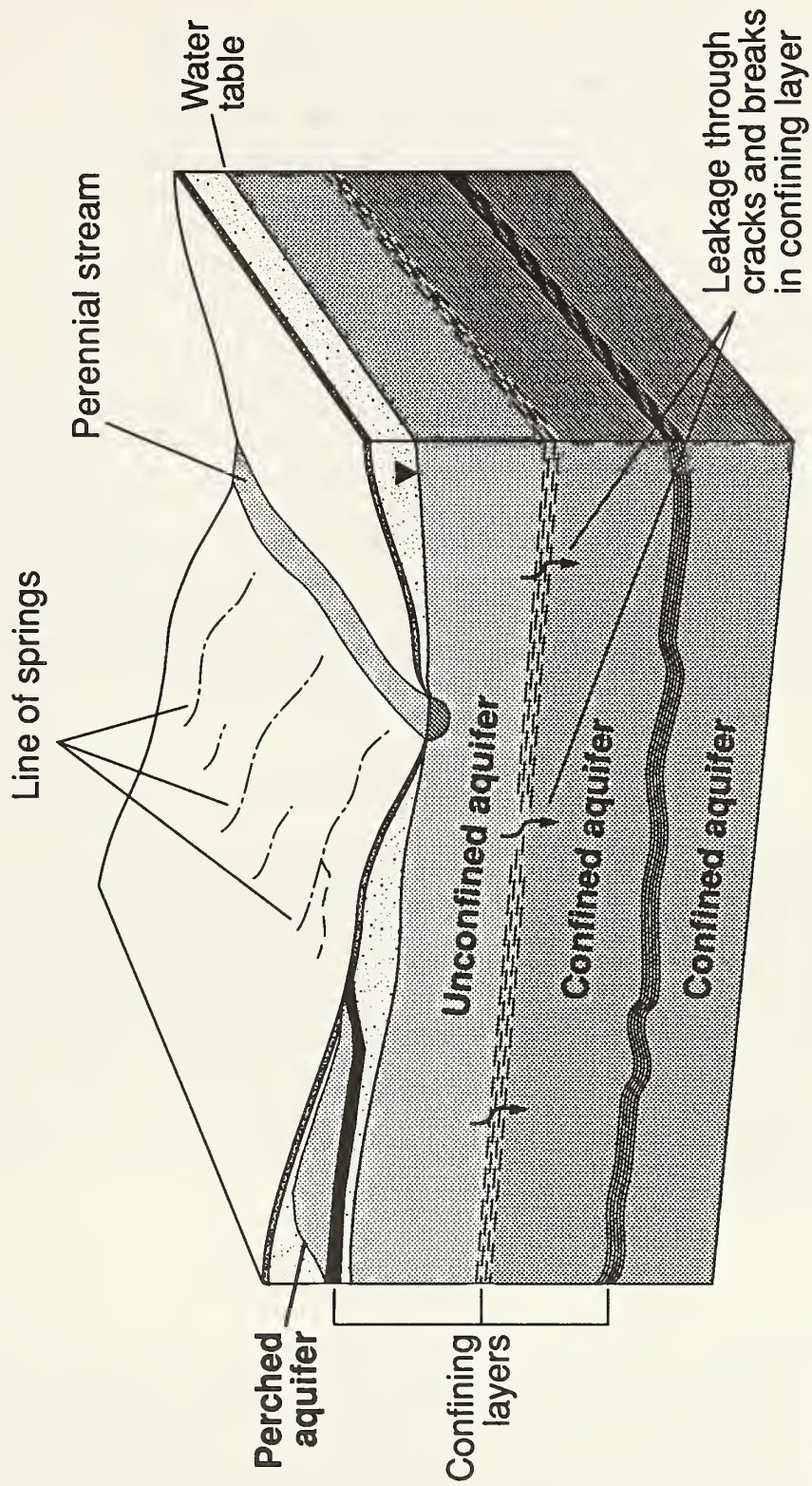
Figure - 6

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Confined Aquifers

Confined aquifers are bounded above and below by barrier zones called confining layers. These **confining layers** are geologic materials which slow or restrict the movement of ground water relative to the adjacent aquifer. Water pressure in a confined aquifer is always greater than the atmospheric pressure. This is because in a confined aquifer the pressure is equal to the sum of atmospheric pressure plus the pressure exerted on the aquifer by the overlying confining layers. As a result, water levels in wells tapping confined aquifers always rise above the top of the aquifer (although not necessarily above the ground surface). These are called artesian wells. Confined aquifers are found below the unconfined aquifer. An aquifer zone can have more than one confined aquifer in it, but only one unconfined aquifer as shown in Figure 6.

Perched Aquifers

Figure 6 also shows **perched aquifers**. These are areas above the water table that can collect a small amount of water over a barrier zone of small areal extent. They generally are not productive sources for drinking water wells.

Aquifer Recharge

Aquifer recharge is the addition of water by percolation to the saturated zone from either the unsaturated zone or directly from surface water. This addition will cause the water table to rise as discussed above. Several aquifers may overlay each other, each with different directions of flow and different sources of recharge. Unconfined aquifers can be replenished over and over after water outputs (pumping, drainage and base flow), by recharge inputs from the surface and from saturated layers below. Confined aquifers are more difficult to replenish because of the confining layers on the top and bottom. Defining the location of aquifer recharge areas may be very difficult if the subsurface geology is highly variable. Subsurface heterogeneity is common in glaciated landscapes such as Michigan and the Great Lakes Basin.

Ground Water Flow

Ground water flow can occur over very large distances. Large aquifers can underlie areas as extensive as 100,000 square miles. In Michigan, the largest regional aquifer is less than one-third this size. The direction of ground water flow may be determined by measuring the elevation of the water surface within a group of wells. The water elevation in each of at least three wells must be known in order to determine the local

flow direction. From these data, contours of equal water surface height can be drawn. The local flow direction is straight down this surface, at right angles to the water-height contours (Figure 7). Determining the direction of ground water flow can help in the resolution of existing pollution problems and aid in identifying vulnerable areas within a region.

Wells

Introduction

A **well** is a column drilled down through the subsurface to the saturated zone. Wells are used as water sources and as monitoring stations for determining the direction of ground water movement. Wells can be set into unconsolidated layers of material, like sand or gravel. These require a **well screen** to exclude the small, loosely packed materials around the well. A well screen is a slotted column beneath the well casing that blocks soil particles from traveling with the water through the pump (Figure 8). Wells drilled into completely consolidated bedrock have no need for a well screen. Typically, well depths in Michigan range from 15 to 500 feet, but most residential wells are less than 200 feet deep.

Aquifer Response To Wells

Confined aquifers and unconfined aquifers respond differently to wells. Water in a well penetrating an unconfined aquifer (Figure 9, Well "a") will rise to an elevation equal to the water table level which is at atmospheric pressure. Correspondingly, water in a well penetrating a confined aquifer (Figure 9, Well "b") will rise above the aquifer to an equilibrium elevation which is proportional to the pressure within the confined aquifer.

Ground Water Flow Direction

A
Well 3
Water elevation
970 feet

Well 2
Water elevation
1010 feet

Well 1
Water elevation
940 feet

Water
table

B Linear interpolation
of water surface
elevations

Well 2
1010 ft

Well 1
940 ft

Well 3
970 ft

Water
table

1000
980
960
1000
980
960

C Contour lines of
equal water surface
elevation

Well 2
1010 ft

Well 1
940 ft

Well 3
970 ft

1000 ft

950 ft

Water
table

D Direction of ground
water movement

Well 2
1010 ft

Well 1
940 ft

Well 3
970 ft

1000 ft

950 ft

90°

Water
table

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Figure - 7

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Water Well Design

Unconsolidated Formation

Top soil

Unconsolidated sand and gravel

Water table

Consolidated Formation

Top soil

Unconsolidated sand and gravel

Water table

Static equilibrium water level

Confining layer

Water-bearing rock

Pump

Well head

Protective casing

Grout seal

Screen

Uncased hole

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Figure - 8

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Wells in the Saturated Zone

Figure - 9

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Unconfined Aquifer Pumping

During pumping of an unconfined aquifer, the water table will be drawn down forming a **cone of depression** around the well column (Figure 10). The water removed from an unconfined aquifer comes not only from the movement of water through the saturated zone, but also from the dewatering of part of this zone, the compressibility of the aquifer material, and the expansion of the water upon pressure release. Above the sloping surface of the water table within the cone of depression, the soil material is no longer saturated with ground water. Below the sloping surface of the water table, ground water moves toward the well until eventually it enters the well screen and is lifted out. When pumping stops, the cone of depression fills with water from below as the aquifer returns to its equilibrium level (the water table). The drawdown around the well, established during pumping, causes an elevation difference which initiates water movement toward the well from surrounding areas. Increasing the pumping rate can enlarge and deepen the cone of depression. For a given set of aquifer characteristics, there is a pumping rate at which equilibrium is reached and the depth of dewatering stabilizes.

Confined Aquifer Pumping

In a confined aquifer, no cone of depression develops within the aquifer as a result of pumping. Pumping can, however, reduce the level to which water will rise in a neighboring unpumped well. Ground water will move toward the pumped well from outside areas, but the entire confined aquifer remains saturated (Figure 11). The water removed from a confined aquifer is accounted for by the expansion of the water upon pressure release and the compressibility of the aquifer material. Water removal from confined aquifers results in compaction of the aquifer material. Unconsolidated materials (e.g. sand & gravel) are subject to more compaction than consolidated materials (i.e. bedrock) because the cemented rock layers usually have a greater inherent strength.

Having completed our discussion of the farm-scale hydrologic cycle, and specifically subsurface water movement, we will now examine the effect of human activities on ground water within the farm-scale hydrologic cycle. We will look at how chemicals enter into and move within the farm-scale hydrologic cycle.

Pumping an Unconfined Aquifer
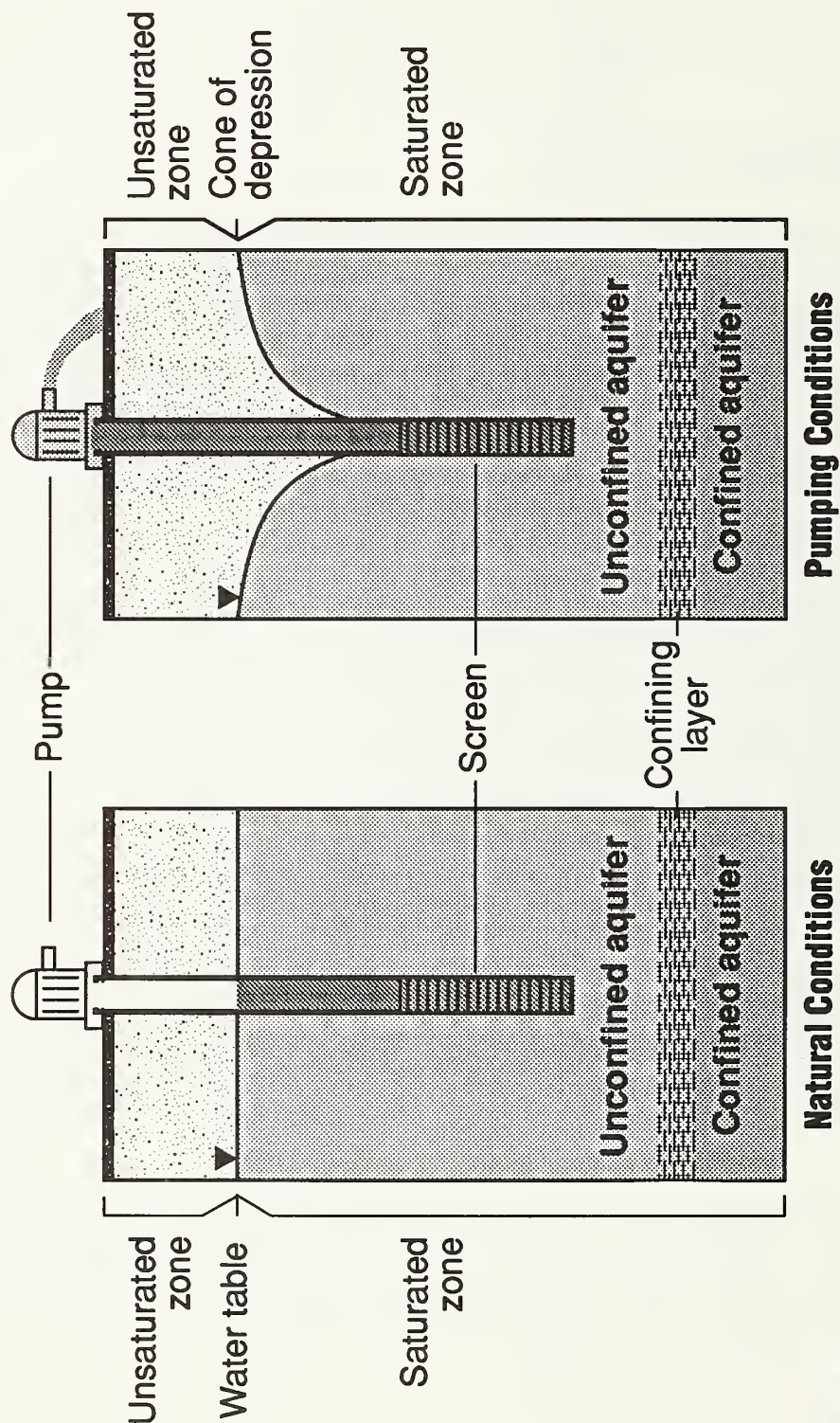
Figure - 10

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Pumping a Confined Aquifer

Unsaturated zone

Water table

Equilibrium water level during pumping

Saturated zone

Unconfined aquifer

Confining layer

Confined aquifer

Pumping Conditions

Unsaturated zone

Water table

Static equilibrium water level

Saturated zone

Confined aquifer

Natural Conditions
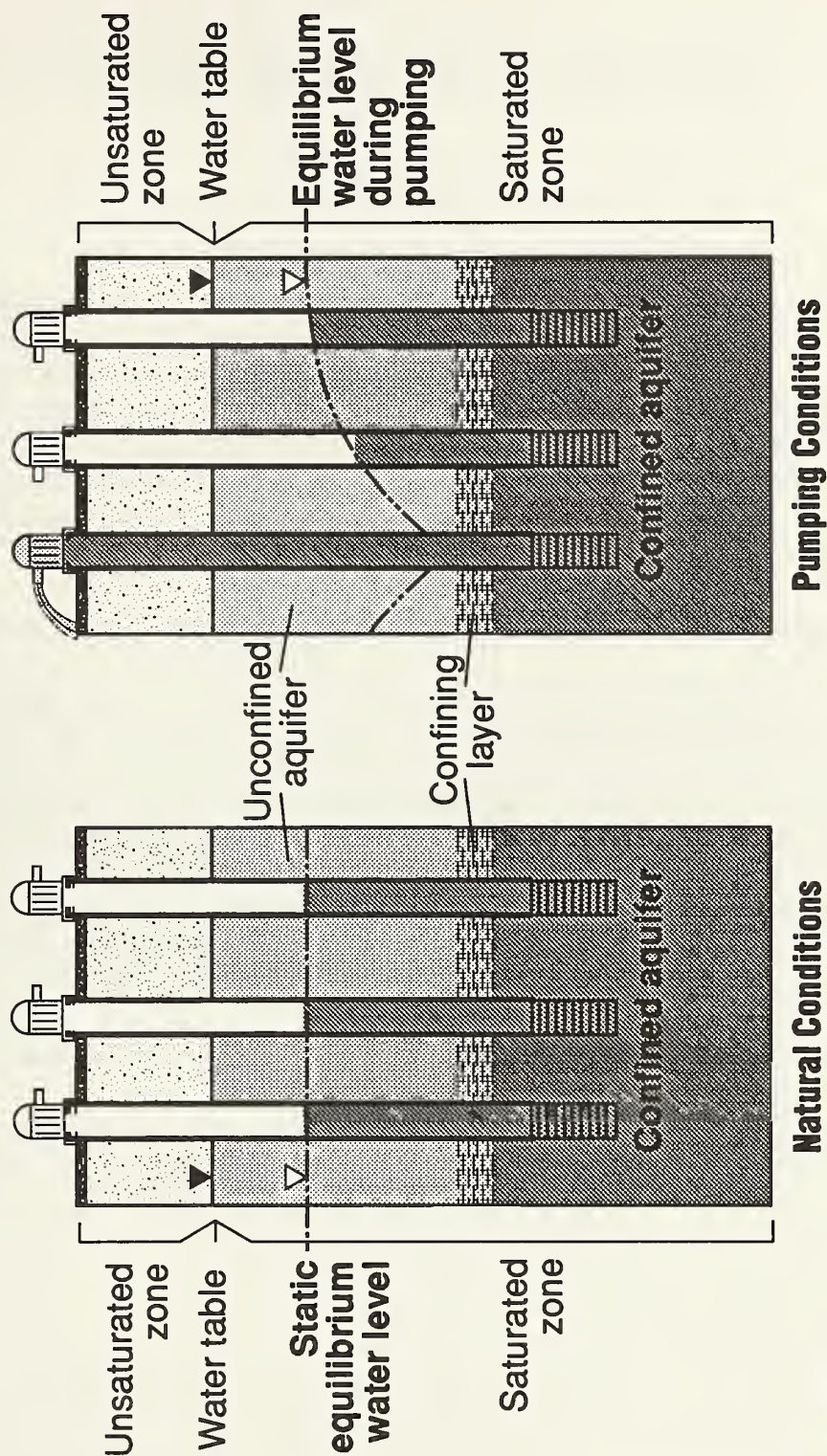
Agriculture's Role in Protecting Ground Water

Figure - 11

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III. CHEMICALS IN THE FARM WATER CYCLE

Introduction

Appropriate management at the land surface is the most effective approach that can be used to protect and improve ground water quality. The land surface or uppermost few tens of feet of the subsurface are the entry ways for most ground water contaminants. It is also the area that land owners can control directly. Land holders who take management steps such as inspecting fuel storage tanks, soil testing for fertilizer application rates, or sealing abandoned wells, can significantly reduce the potential for degradation of our farm-water resources.

Chemical Application, Contaminant & Pollutant Definitions

A chemical application is the spreading of a chemical on the land surface or incorporating it into the plow layer of a field. Examples of chemical applications include spraying a weed killer on your lawn, spraying a road surface to reduce dust or incorporating anhydrous ammonia as a nitrogen fertilizer. A contaminant or pollutant is any chemical within the farm-water cycle that has moved away from the area of its intended use and is present in water in concentrations defined as unacceptable considering the water's intended use. *Pollution* can then be defined as any reduction of the quality of water beyond levels established as safe for the intended use.

Sources Of Concentrated Chemical Pollutants In Ground Water

Ground-water pollution is caused by a wide variety of business, industrial, farm, and household activities. Some examples of businesses and industries which have contributed to ground-water pollution include: dry cleaners, paper processors, metal coating companies and gas stations. Examples of ground-water pollution contributions from farm operations include: farm chemical spills during mixing and loading, excessive fertilizer and pesticide applications, inappropriate manure storage techniques and improper disposal of farm chemical residuals and containers. Examples of household contributions to ground-water pollution through the improper use or disposal of chemicals include: paint thinners, used motor oil, drain openers and discharge of water softeners. A few gallons of unwanted gasoline, when dumped on the ground, can pollute the drinking water of an entire community.

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These scenarios of concentrated chemical entry into the water cycle are examples of **point source pollution**. Point source pollution is characterized by high concentrations over a small area or at a point. These sources can cause acute problems because their high concentrations in water can cause immediate health risks. Point source releases in the area of a well can quickly increase contaminant concentrations in the well water to levels above those established for safe consumption. Point source pollution is generally accidental. Through increased awareness and safer practices, the number of point source pollution problems could be reduced.

Chemical Contaminants In Ground Water From Chemical Applications

Chemical applications for agriculture are characterized by low concentrations over a large area. Correctly applied farm chemicals are designed to perform a task in the soil as part of an efficient production system. But, in certain situations, even correctly-applied farm chemicals can add contaminants into the farm-water cycle and contribute to reductions in water quality. An example of this is if a very heavy rain occurs soon after a fertilizer application. Such a situation may cause water with dissolved chemicals (the fertilizer) to run off into surface waters or move downward through the root zone into the underlying saturated zone.

Any amount of chemical added to the soil that is not taken up by plant roots, removed by soil microbes, or held in the unsaturated zone, becomes a potential contaminant within the farm water cycle. These contaminants may eventually reach ground water, where they can remain for years. This type of contamination in ground water can be considered **nonpoint source pollutants** if their concentration exceeds recommended levels. This is considered a chronic (as opposed to acute) problem because of the characteristic low concentration of the chemical that persists over a long time period. Little is known about the long term health effects of consuming water that has low concentrations of chemicals. It is for this reason that appropriate land management must be stressed to reduce the potential for contamination of farm water resources.

Naturally Occurring Ground Water Chemicals

Many compounds are found naturally in ground water. Water soluble minerals like calcite and feldspar are common in soils. In contact with water, these minerals dissolve into their compounds and travel with the water flow. Even naturally occurring dissolved elements in water can become hazards to consumers. In some areas, unacceptably high levels of dissolved minerals make the water undrinkable. Recommended drinking water standards, which specify maximum concentration levels, have been established for both

naturally occurring chemicals, as well as man-made pollutants. In addition, the EPA has established Health Advisory limits for many pesticides. Examples of these are given in the appendix.

Chemical Transport

Movement, Through Water, Away From The Unsaturated Zone

After a chemical application, transport can begin with an addition of water to the ground surface, generally as rain or irrigation. The soluble chemicals on the surface dissolve with the water and begin to travel. Infiltration to the unsaturated zone will begin as rainfall starts. When infiltration cannot keep pace with the rainfall, surface runoff will begin, and water and sediment with chemical particles will begin to travel toward surface waters (e.g. streams, ponds, or lakes). As the unsaturated zone fills, downward movement of chemicals toward the saturated zone will begin.

Chemical Removal From The Unsaturated Zone

Several processes within the unsaturated zone can reduce the amount of fertilizer or pesticide found in the unsaturated zone beyond what plant roots absorb. Chemicals can be broken down by chemical or microbial action within the unsaturated zone. Most chemicals used for farming are not chemically stable. When put into the environment they break down within days or weeks into chemically simpler, more inactive forms. Other chemicals become volatile when placed in the soil, and can move out of the soil into the atmosphere as a gas. Still other chemicals are attracted to soil particles, such as clays and organic matter and can become attached (adsorbed, i.e. chemically bonded) to them. These actions help remove chemicals from the soil and slow chemical movement into the subsurface water resources.

Any time an applied chemical leaves the unsaturated zone by movement with water or becomes unavailable for plant use by a chemical process, it has left by a loss pathway (Figure 12). Table 3 lists the loss pathways available for contaminant movement and reduction. Movement of point source pollution and reductions in these chemical concentrations can occur in the same manner.

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Loss Pathways Through the Hydrologic Cycle

Volitization

Surface runoff

Stream

Surface runoff

Infiltration

Chemical process zone

Water table

Ground water

Confining layer

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Figure - 12

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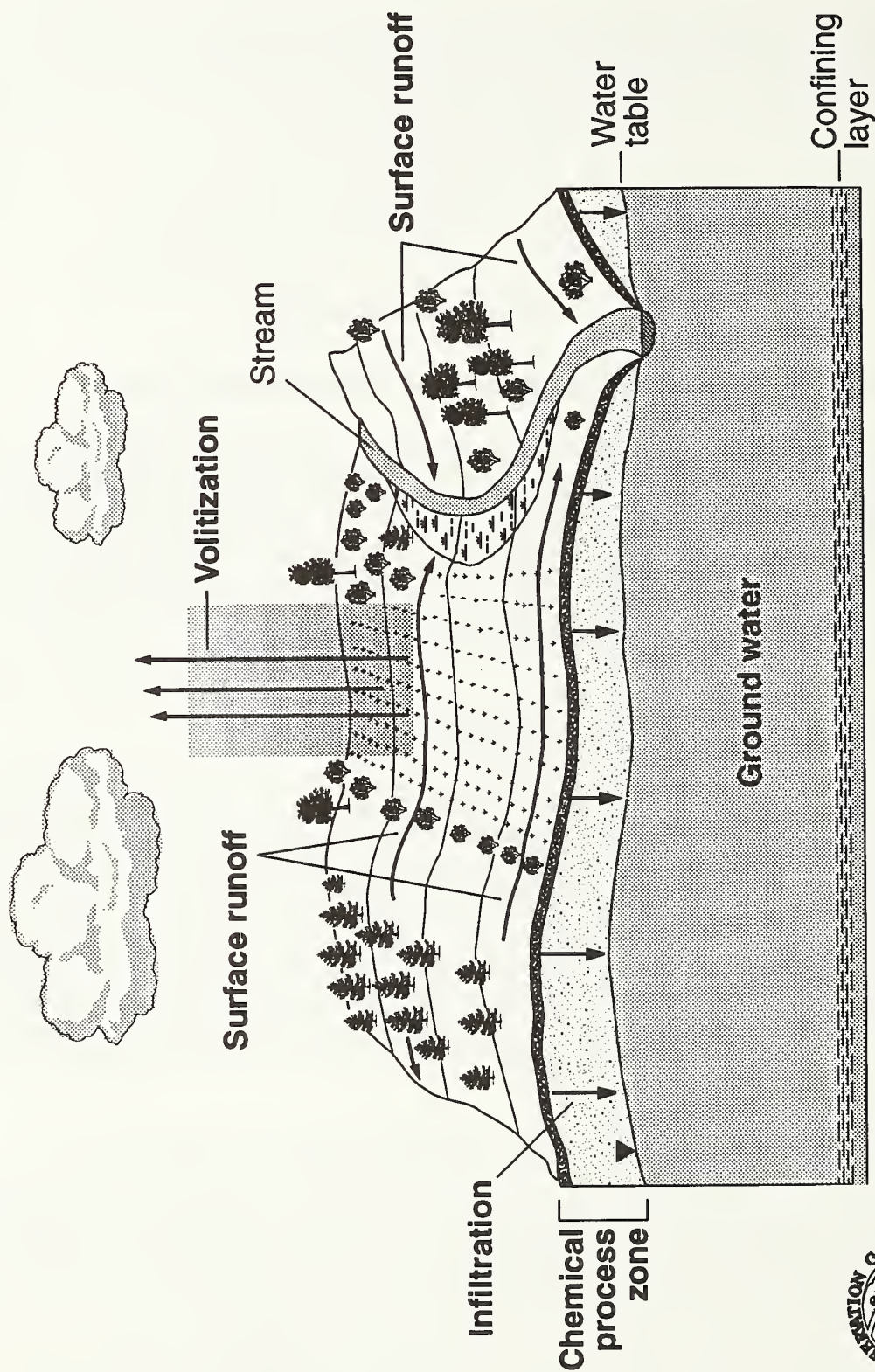
Table 3. Loss Pathways for Contaminant Movement and Reduction

1. Surface To Atmosphere

   - Chemical Reduction Due To Volatility

2. Surface To Surface

   - Surface Runoff

3. Unsaturated Zone

   - Movements From Upper Portion To Lower Portions of the subsurface zone

   - Chemical Degradation, Plant Uptake

   - Adsorption To Soil Particles

4. Unsaturated to Saturated Zone

Contaminant Movement In The Aquifer Zone

Contaminants From Chemical Applications

Contaminants that travel down to the saturated zone in water enter the aquifer at lower concentrations, over a larger area, compared to those from point sources (Figure 13). After entering the aquifer zone, these contaminants begin to travel in the direction of primary ground water flow. Contaminant concentrations will be reduced as mixing occurs with the aquifer water. As a result of mixing, contaminants may soon be spread over wide areas of an aquifer. Once an aquifer is contaminated from a nonpoint source, removal of the pollutants from the aquifer itself is almost impossible. Point-of-entry or point-of-use remediation devices may be the only practical solution in these circumstances.

Point Source Pollutants

The region of point source pollutant concentration within an aquifer zone is called a plume. The plume describes a three-dimensional zone of contamination, at some specified level of concentration(s), which moves with the ground water. The majority of the plume movement is in the direction of the normal water flow. Concentrations of the contaminant within the plume vary due to mixing and dilution with the ground water. Pollutants can enter the aquifer as either 1) a continuous release over a long period of time or 2) as a concentrated slug of pollutant that is released, more or less all at once, into the aquifer. For continuous sources (Figure 14), higher concentrations will be found near the point of entry to the aquifer with progressively lower concentrations, especially along the plume front and edges, being found down gradient. This spatial pattern of concentration can be helpful for tracing the plume back (up-concentration) to its source. In the case of a slug release, on the other hand, the highest concentrations of the pollutant reside near the center of the plume, with lessening concentrations in all directions. This volume of contaminated water travels down-flow, away from the point of entry into the aquifer (Figure 15). This almost "capsulated" spatial pattern makes it very difficult to definitively locate the original source of the problem in most circumstances. In contrast to nonpoint source pollution of ground water, the smaller areal extent of the contamination that is typical of a point source contaminant plume does make its cleanup more feasible, but the costs are great nevertheless. There is widespread consensus that prevention of ground water contamination is vastly less expensive than remediating contaminated aquifers.

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Contaminant Movement to Aquifer

Top soil with chemical application

Top soil without chemical application

Chemical

Infiltration

Top soil

Root zone

Unsaturated zone

Water table

Saturated zone

Regional ground water flow

Agriculture's Role in Protecting Ground Water

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Figure - 13

29
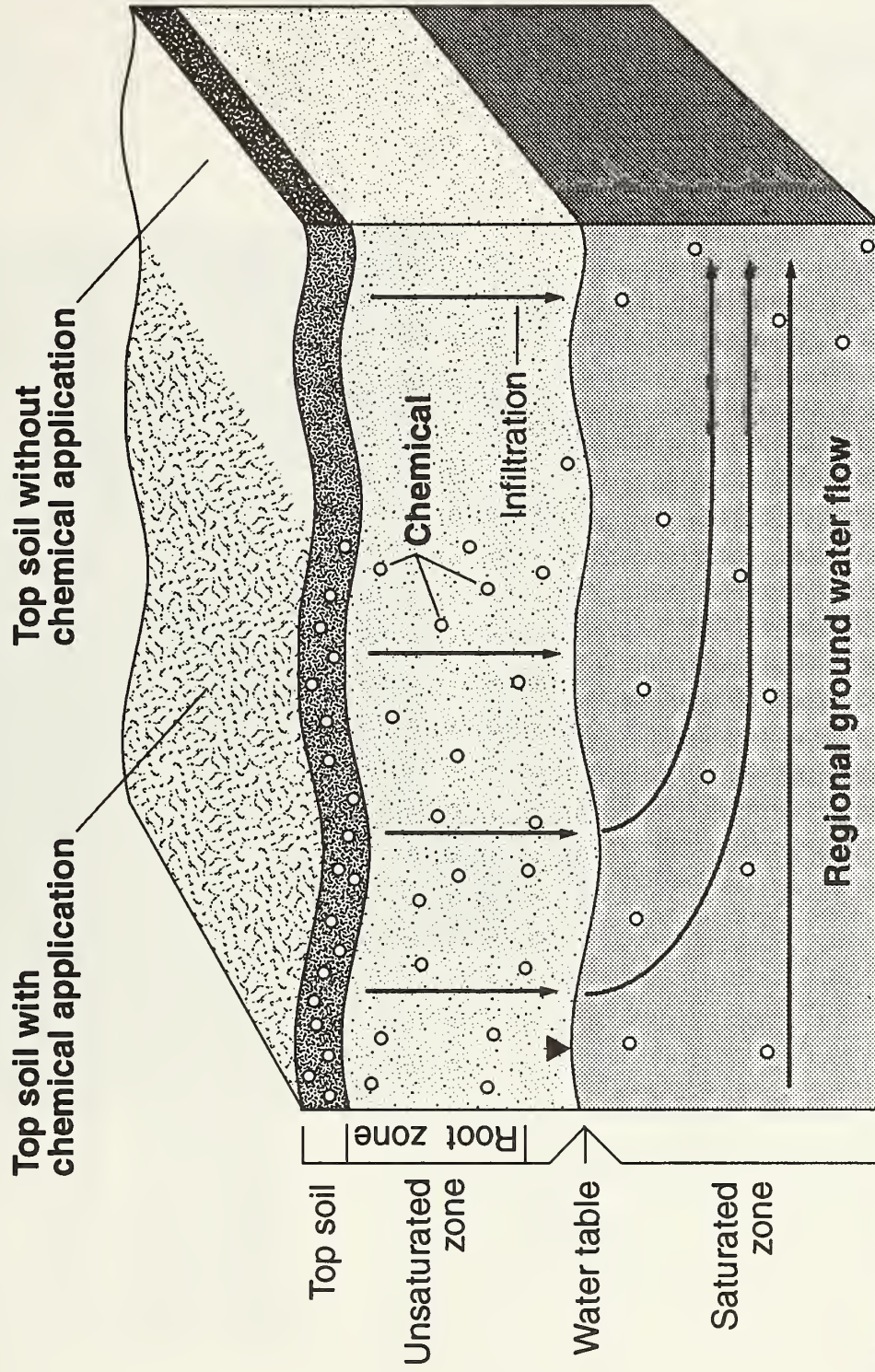
Continuous Source Pollution Plume

Infiltration

Continuous source of contamination

Pollution plume

Unconfined aquifer

Confining layer

Confined aquifer

Unsaturated zone

Water table

Saturated zone

Regional ground water flow

Seepage into confined aquifer through fracture
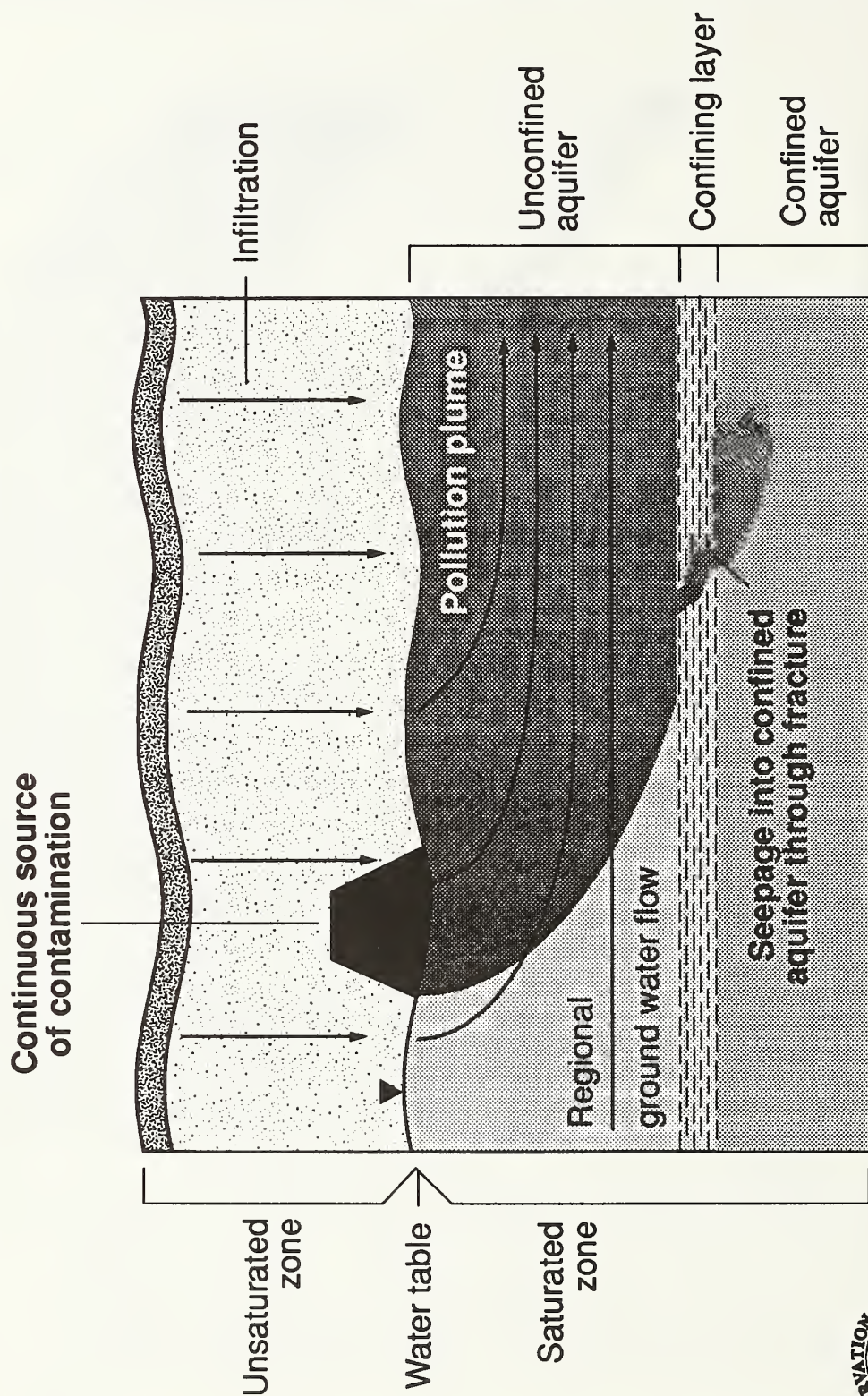
Figure - 14

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CONSERVATION GEM

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Pollution Pattern from Slug Releases

Time = 0   Pollution source point

Well

Ground water flow

Pollution

Time = 1

Well

Well

Pollution

Time = 2   Well drawing polluted water

Well

Pollution

Figure - 15

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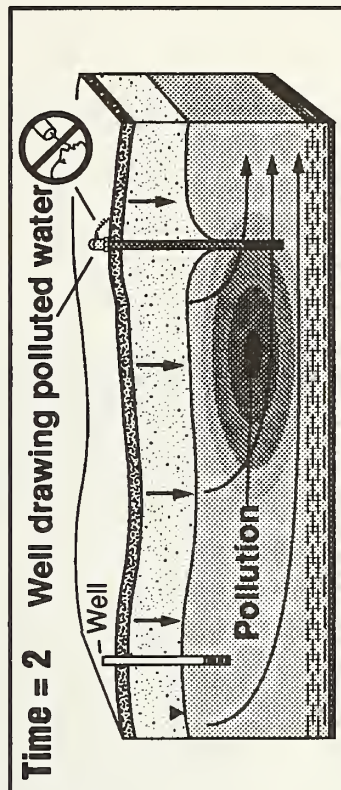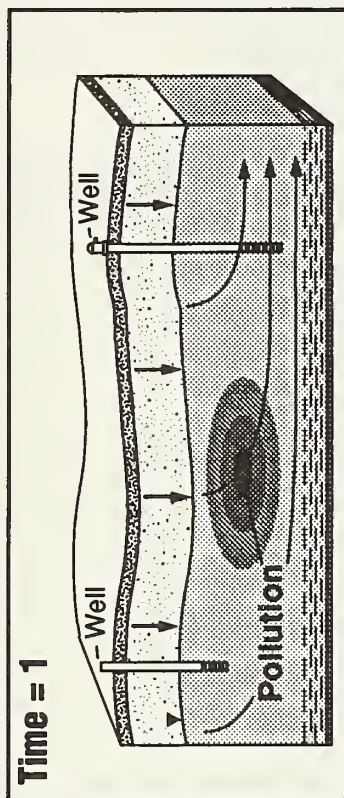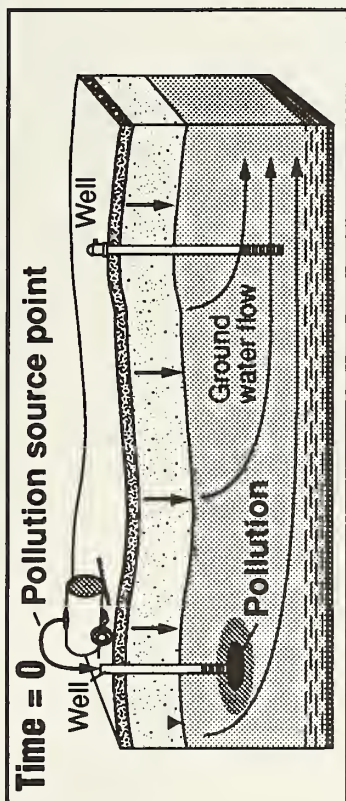
Wells In Contaminated Regions

A pumped well which taps a contaminated region of an aquifer has the potential to pull either high-concentration pollutants (typical of point sources) or lower-concentration contaminants (typical of nonpoint sources) directly into the well (Figure 16). Contaminated water in the aquifer zone travels by the same mechanisms discussed above for confined and unconfined aquifers. If the well supplies drinking water for human or animal consumption, it may pose a serious health risk. Many of the potential contaminants are tasteless, colorless, and odorless, so their presence in the water may go undetected for long periods. From the standpoint of safeguarding human health, *preventing* ground water pollution before it becomes a problem is clearly the best option.

Pumping Well Drawing in Contaminants

Infiltration

Point source pollutant

Farm chemical application

Pumping well

Top soil

Unsaturated zone

Water table

Saturated zone

(Unconfined aquifer)

Local ground water flow

Pollution plume

Chemical contaminant

Regional ground water flow
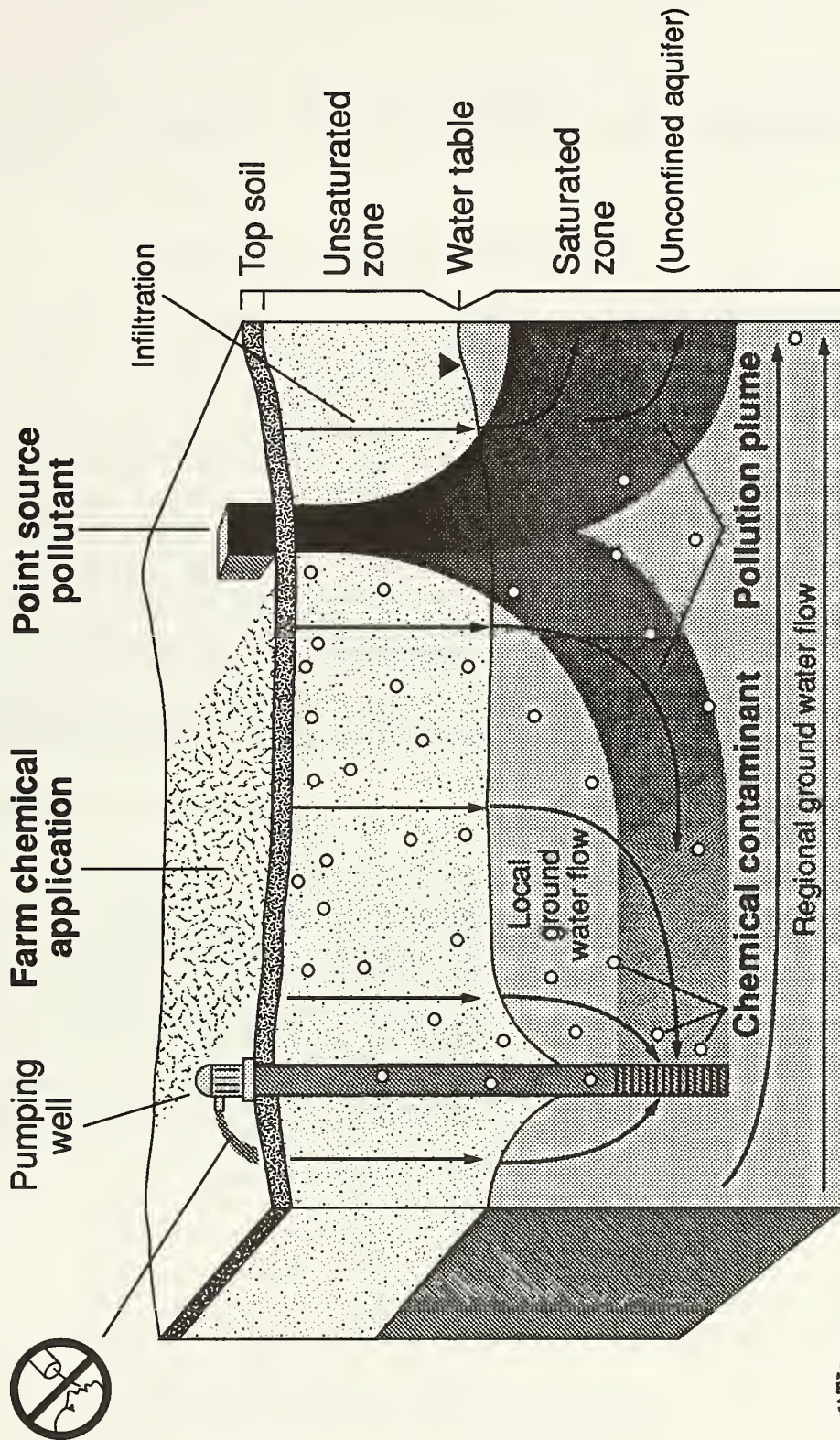
Figure - 16

Agriculture's Role in Protecting Ground Water

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IV. METHODS FOR PROTECTION OF GROUND WATER QUALITY

Farm Water Quality Management

Best Management Practices (BMPs) For Ground Water Protection

It is impossible to accurately predict water inputs at the surface and water movement within the subsurface. Accordingly, it is not possible to accurately predict the amount of contaminant, if any, which might escape through the unsaturated zone (and, hence, reach the ground water) following any type of chemical application on the surface. Nevertheless, we can make changes in our day-to-day activities at home and at work, both on and off the farm, which will reduce the risk of useful chemicals becoming contaminants in our ground water. An assessment of the potential pollution problems on your farm is easily implemented. Effective, enlightened management of nutrients (including manure), pesticides and irrigation water, for example, are excellent BMPs to reduce the potential for ground water contamination. Table 4 lists numerous considerations which are possible components of a farm-water quality management strategy.

Site Assessment

The first step needed to reduce the risk of ground water contamination is to learn about potential sources of contamination at the farm site and in the surrounding area. For a farm site assessment procedure, a questionnaire such as the *Water Quality Self-Help Checklist* published by the American Farm Bureau Federation can help. Potential point source pollutants include fuel storage tanks, pesticide and fertilizer storage facilities and animal waste storage structures. Potential nonpoint source pollutants include septic systems and the chemicals applied to farm fields or lawns. The well location and its proximity to these sources of pollution is an important factor also.

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Table 4. Components Of A Farm-Water Quality Management Plan

1.   **Current And Potential Water Sources:**

        groundwater
        surface water

2.   **Previous Water Test Results**

3.   **Climate, especially average rainfall**

4.   **Subsurface Conditions**

        bedrock type and depth
        top soil thickness
        soil properties
        depth to water table
        active and inactive well history

5.   **Surface Water Storage and Recharge Conditions**

6.   **Facilities Situation**

        common well for livestock & household uses?
        confined feedlot location relative to well
        manure lagoon or holding facility location relative to well
        septic tank and septic field location relative to well
        age and maintenance history of fuel storage tanks,
        especially underground tanks

7.   **Facilities and Operations Management Practices**

        septic system age and maintenance history
        surface water drainage methods
        irrigation/chemigation practices/record keeping
        nutrient/pesticide application practices/record keeping
        manure/sewage application practices/record keeping
        soil test results/record keeping
        crop nutrient budgets and yield goal setting

Nutrient And Pesticide Management

Ideally, nutrients will be applied to a crop or lawn with accurate timing and at the correct rate to meet plant nutrient needs while having very little nutrient left over to potentially be carried away from the intended site. Management of commercial fertilizers and animal manure will help meet that objective. This includes:

* soil testing and establishing realistic yield goals to set fertilizer requirements

* taking credits for nutrients from legume crops and animal manure

* timing/split applications to meet crop needs

Likewise, it is the ideal situation that pesticides will be applied at times and rates which will produce efficient pest control with minimal damage to the crop *and* minimal adverse off-site effects. Pesticide management involves choosing the best chemical for the job and applying it according to label directions. Be aware of the vulnerability factors which could affect how easily a chemical will move with water to the saturated zone or to surface waters. These include:

* soil -- sandy or clay-rich
          -- ease of drainage
          -- amount of organic matter

* site -- depth to water table
         -- abandoned wells nearby
         -- fractured or soluble bedrock in the area

* chemical -- adsorption capability
             -- persistence

* management -- tillage method
               -- proper application techniques
               -- proper disposal of containers and remainder
               -- Integrated Pest Management (IPM) alternatives

The brochure *Treasure Of Abundance Or Pandora's Box? A Guide for Safe, Profitable Fertilizer and Pesticide Use* (Soil and Water Conservation Society, no date) provides an expanded discussion of nutrient and pesticide management. The local technical staff of the Soil Conservation District / Soil Conservation Service and your county Extension Service can help you plan a nutrient and pest management system.

Irrigation Management

Irrigation water management can play an important role in managing chemical movement. Irrigation should be applied in amounts sufficient to just meet plant needs. If excess water is applied there is a greater chance of leaching or runoff, which could carry chemicals off-site to ground water or surface waters. Irrigation scheduling is an important component of farm water quality management.

Well Head Protection And Management

Limiting the use of the land immediately around the well and ensuring proper maintenance and security of the well is called well head protection (Figure 17). Activities such as mixing and loading of chemicals or rinsing of equipment in the area immediately surrounding a well puts the water supply at greater risk than if these activities were done in areas away from the well. A spill in the well head zone could quickly contaminate well water and result in the loss of the well and permanent damage to the aquifer. Contamination can also occur at the well head from improper construction or direct injection into the well. Poor well construction can allow contaminants to travel down from the surface along the outside wall of the well casing where they may quickly be pumped back to the surface. Direct injection can occur by accidental back siphoning from a spray tank. The need for extreme care around wells can not be overemphasized.

Management for the well-head area includes many simple precautions:

* ensure the well head is properly sealed to avoid direct injection

* inspect the well-head casing for cracks that might allow contaminants to enter

* mix and load chemicals at least 100 feet from the well

* install a check valve on filling lines to prevent back-siphoning while filling a spray tank

* ensure that all abandoned wells are properly sealed

Consult your local health department for information on well-water testing and proper well construction and abandonment standards and methods.

Well Head Protection

Zone of influence   Well head protection area (WHPA)

Pumping well

Infiltration

Unsaturated zone

Water table

Saturated zone

(Unconfined aquifer)

Confining layer

Well head protection area

Zone of influence

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Figure - 17

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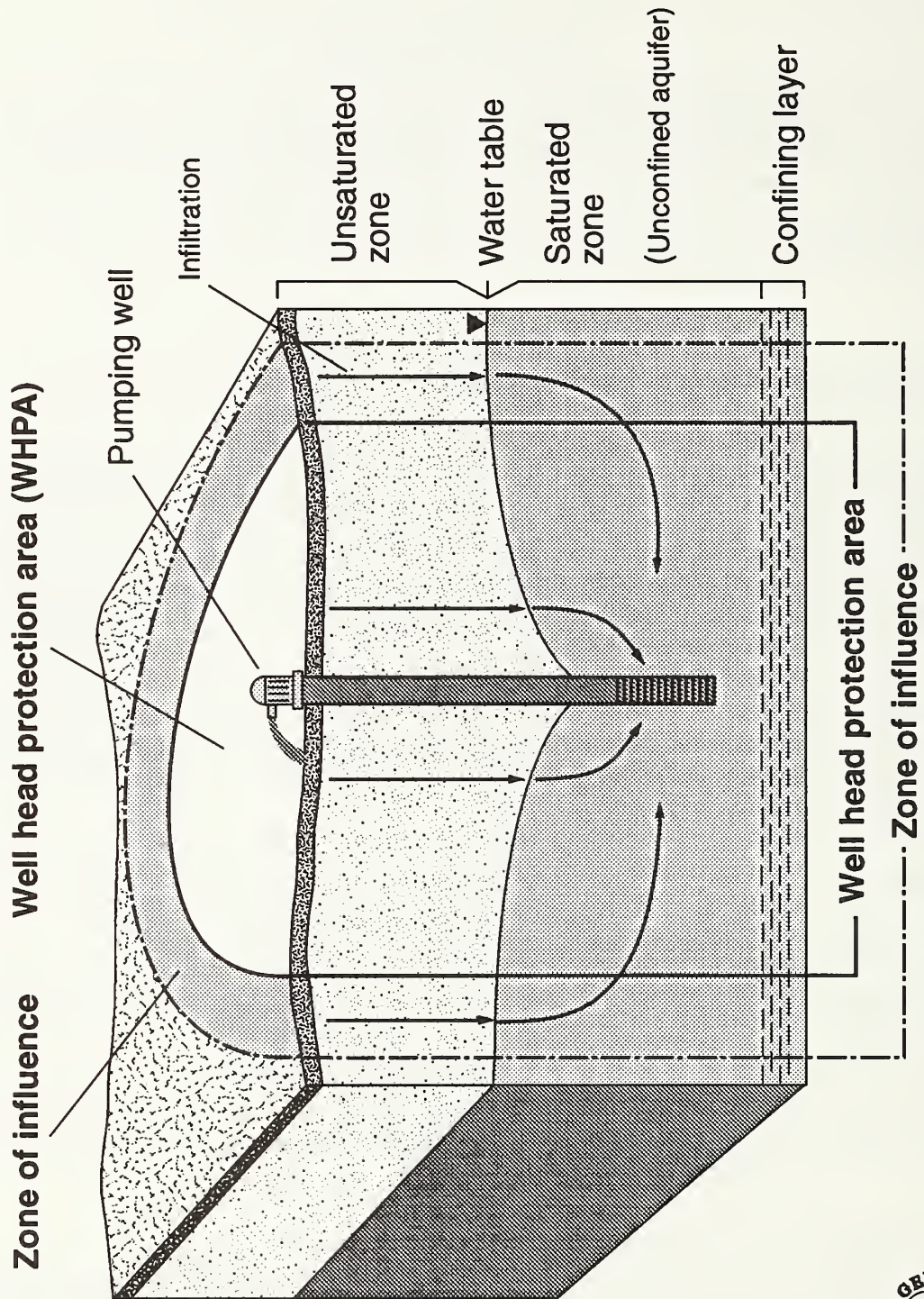
V. APPENDIX

Maximum Contaminant Levels (MCLs) for Pesticides

Pesticide Type	Interim MCL (ppb) *	Proposed MCL (ppb)
Alachlor	-	2
Aldicarb	-	10
Aldicarb Sulfone	-	40
Aldicarb Sulfoxide	-	10
Atrazine	-	3
Carbofuran	-	40
Chlordane	-	2
2,4-D	-	70
DBCP	-	0.2
Dichloropropane (1,2-)	-	5
Endrin	0.2	-
Ethylene dibromide (EDB)	-	0.05
Heptachlor	-	0.4
Heptachlor Epoxide	-	0.2
Lindane	4	0.2
Methoxychlor	100	400
Pentachlorophenol	-	0.1
Toxaphene	5	5
2,4,5-TP Silvex	10	50

* ppb = parts per billion
National Interim Primary Drinking Water Standards, 1986
Proposed MCLs from *Federal Register* , Vol 54: 22062-22160, May 22, 1989

Maximum Contaminant Levels for Inorganic Chemicals

Contaminant	MCL (ppb)*
Arsenic	50
Barium	1000
Cadmium	10
Chromium	50
Fluoride	2.2
Lead	50
Mercury	2
Nitrate (as N)	10[++]
Selenium	10
Silver	50

* ppb = parts per billion
[++] parts per million (ppm)
Source: National Interim Drinking Water Standards (c. 1978)

Recommended Limits for Livestock and Irrigation Water

	Livestock Recommended Limits (ppm)	Irrigation Crops Recommended Limits (ppm)
Total dissolved solids		700
Small animals	3000	
Poultry	5000	
Other animals	7000	
Nitrate	45	--
Arsenic	0.2	0.1
Boron	5	0.75
Cadmium	0.05	0.01
Chromium	1	0.1
Fluoride	2	1
Lead	0.1	5
Mercury	0.01	--
Selenium	0.05	0.02

Source: **U.S. Environmental Protection Agency (c. 1973)**

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Health Advisories for Selected Pesticides

Chemical Name	Other Name	Health Advisory Level (ppb)[*]
2,4-D		70
Alachlor	Lasso	40[+]
Aldicarb	Temik	10
Atrazine	AAtrex, Gesaprin, Zeaphos	3
Bromacil	Borea, Bromex, Urox B	90
Carbofuran	Furadan	40
Chlordane	Chlordan, clordano	3[+]
Chlorothalonil	Bravo	200[+]
DCPA, chlorthal dimethyl	Dacthal	4000
Diazinon		0.6
Dibromochloropropane, DBCP		3
Dicamba	Banuel	200
Dichloropropane (1,2-)	1,2-D	60[+]
Dichloropropene (1,3-)	1,3-D	20[+]
Dieldrin		0.2[+]
Diuron		10
DNBP	Dinoseb, Dinitro	7
Ethylene dibromide, EDB		0.04[+]
Fonofos	Dyfonate	10
Hexazinone	Velpar	200
Lindane	Gamma BHC or HCH	0.2
Methomyl	Lannate	200
Methyl parathion, parathion-methyl		2
Metolachlor	Dual	100
Metribuzin	Sencor	200
Oxamyl	Vydate	200
Picloram	Tordon	500
Prometon	Pramitol	100
Propazine	Milogard, Pramitol P	10
Simazine	Princep	4
Toxaphene		3[+]
Trifluralin	Treflan	2

[*] ppb = parts per billion
[+] based on one in ten thousand lifetime cancer risk
source: USEPA, Office of Drinking Water. 1989. Drinking Water Standards and Health Advisories (DRAFT).

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Freeze, R.A., J.A. Cherry. 1979. **Groundwater.** Prentice-Hall: Englewood Cliffs, NJ.

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Heath, Ralph C. 1987. **Basic Ground-Water Hydrology.** U.S.Geological Survey Water-Supply Paper 2220. U.S. Geological Survey, Books and Open-File Reports Section, Federal Center, Box 25425, Denver, CO. 80225.

Northeast Regional Agricultural Engineering Service. 1989. **Pesticides and Groundwater : A Guide for the Pesticide User.** NRAES-34. NRAES, Cooperative Extension, 152 Riley-Robb Hall, Ithaca, N.Y. 14853, (607) 255-7654.

Soil and Water Conservation Society. No Date. **Treasure of Abundance or Pandora's Box? A Guide for Safe, Profitable Fertilizer and Pesticide Use.** Soil and Water Conservation Society, 7515 Northeast Ankeny Road, Ankeny, Iowa 50021, (515) 289-2331.

U.S. Department of Agriculture, Soil Conservation Service. 1987. **Principles of Ground Water for Resources Management Systems, Field Level Training Manual.** Engineering Staff, South National Technical Center, SCS, Box 6567, Fort Worth, TX 76115.

U.S. Environmental Protection Agency. 1989. **Nonpoint Sources Agenda For The Future.** Office of Water, Washington, D.C.

University of Wisconsin - Extension and the Wisconsin Department of Agriculture. 1989. **Nutrient & Pesticide Best Management Practices For Wisconsin Farms.** WDATCP Technical Bulletin ARM-1. University of Wisconsin - Extension: Madison, WI.

VII. WATER QUALITY AND RELATED TOPICS
Additional Resources and Information
compiled by
Ruth Shaffer
July, 1990

MSU Cooperative Extension Service Publications

WQ01	Handling/Underground Storage of Fuel
WQ02	Guidelines for Testing of Private Wells
WQ03	Managing Organic Soils to Reduce Nonpoint Source Pollution
WQ04	Managing Pesticides to Avoid Surface and Groundwater Contamination
WQ05	Phosphorus: Pollutant and Essential Plant Food Element
WQ07	Nitrogen Fertilizer Management
WQ08	Understanding Sediments: Problems and Solutions
WQ09	Nitrogen Management Strategies for Potato Producers
WQ12	Livestock Manure Management for Crop Production and Water Quality
WQ13	Maintain Your Septic System - Shoreline Property Owners
WQ14	What To Do If Your Septic Tank Fails
WQ15	Find Out About Water and Septic Systems If Buying/Selling a Home
WQ16	How to Conserve Water in Your Home and Yard
WQ18 *	An Introduction to Michigan's Water Resources
WQ19	Nitrate - A Drinking Water Concern
WQ20	Agriculture and Water Quality in Michigan - Spring 1989
WQ21 *	A Guide to Home Water Treatment
WQ22	Distillation for Home Water Treatment
WQ23	Home Water Treatment Using Activated Carbon
WQ24	Reverse Osmosis for Home Treatment of Drinking Water
WQ25	Nutrient Management to Protect Water Quality
WQ26	Managing Pesticides on Corn to Avoid Contaminating Water
WQ27	Managing Pesticides on Dry Beans to Avoid Contaminating Water
WQ28	Managing Pesticides on Christmas Trees to Avoid Contaminating Water
WQ29	Managing Pesticides on Hay and Forage to Avoid Contaminating Water
WQ30	Managing Pesticides on Potatoes to avoid Contaminating Water
WQ31	Managing Pesticides on Soybeans to Avoid Contaminating Water
WQ32	Managing Pesticides on Small Grains to Avoid Contaminating Water

* = for sale only

Other Available Publications and A/V Materials

Erosion and Water Quality Guides for Forestland and Timber Harvesting.
U.P. R.C. & D. 1990.

Groundwater and Agricultural Chemicals. [VHS videotape, 17:40 minutes]
Soybean and Corn Growers Association. 1987.

Importance of clean water and farm chemicals to agriculture and attaining a
balance between pesticides and groundwater.

Groundwater: The Unseen Resource. [VHS videotape, 19:00 minutes]
MSU, Cooperative Extension Service. 1989.

Provides an introduction to groundwater resources in Michigan and to
groundwater hydrology, chemical constituents, and contamination.

Agriculture and Groundwater Contamination: Exploring the issues. [VHS videotape,
17:30 minutes]. MSU, Cooperative Extension Service. 1989.

Provides an overview of groundwater contamination concerns in Michigan
agriculture.

Groundwater and Your Family's Health. [VHS videotape, 15:00 minutes]
MSU, Cooperative Extension Service. 1989.

Reviews the groundwater resources of Michigan, groundwater's chemical makeup,
health effects of contaminants, and solutions to contamination problems.

Understanding Groundwater: The Hidden Resource. [140 slides, audio tape 24:30
minutes, and text]. National Association of Conservation Districts, 1984.

Basic facts and terms about groundwater. Water management, contamination, its
importance to agriculture and industry.

Now We Know. [80 slides, 20 minute audio tape, script]
Ed Lamb and Associates, 1985.

An overview of the problems of water pollution from nonpoint sources and some practical solutions.

Protecting Groundwater: A guide for the Pesticide User. [63 slides, script]
Cornell University, 1988.

Defines groundwater, how pesticides contaminate it, ways to reduce contamination and potential health effects.

Pesticides and the Environment. [64 slides, script]
MSU - Cooperative Extension Service, 1989.

Overview of recent well testing programs in Michigan, how pesticides contaminate groundwater, possible impact of conservation tillage on water quality, and ways to reduce contamination potential.

VIII. GLOSSARY OF HYDROLOGIC TERMS

Anisotropic aquifer   an aquifer in which the magnitude of hydraulic conductivity varies with direction.

Aquifer   a soil or rock formation which is capable of storing and transmitting a usable amount of ground water to the surface.

Artesian well (flowing)   a well in a confined aquifer that has a water level above the ground surface due to the confining pressure.

Baseflow   ground water discharge on the land surface, usually to streamflow.

Capillary fringe   a transitional region between the saturated and unsaturated zone which is partially saturated from suction pressure of the unsaturated zone.

Compaction   the reduction of confined aquifer thickness due to water pumping.

Cone of depression   the lower boundary of the unsaturated region which develops around a well during pumping.

Confined Aquifer   a formation in which the ground water is enclosed above and below by a confining layer of low hydraulic conductivity; the confined ground water is usually held a pressure greater than atmospheric.

Consolidated   subsurface geologic materials which have been compacted and cemented by various natural processes; in general, the bedrock.

Darcy's Law   a description of the rate of water flow through a column of soil based on the hydraulic conductivity of the soil and the cross sectional area of the column.

Discharge   natural outflow of water from the saturated zone.

Drawdown   the magnitude of the lowering of the water table directly around a pumped well. The distance between the static water level and the cone of depression.

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Effluent Stream a perennial surface stream that has a component of it's total flow supplied by groundwater (baseflow). Also called *Gaining Stream.*

Elevation head the fluid pressure at a specific point above a datum (i.e. reference elevation).

Equipotential line a contour line connecting points of equal hydraulic head within the groundwater flow field.

Evaporation the process by which a fluid changes from liquid to vapor phase.

Evapotranspiration the combined amount of water vapor from surface evaporation and plant transpiration.

Field capacity the maximum amount of water that can be held in the soil pores of the unsaturated zone (includes the root zone) against the force of gravity.

Flow line a line describing the direction of water flow in the subsurface; it is always perpendicular to the equipotential lines.

Free water surface the water table, the top surface of the unconfined saturated zone.

Ground water the subsurface water that completely fills the pore spaces of soils and void spaces of rock formations beneath the water table.

Ground water pollution the degradation of the ground water quality to an unacceptable level in light of an intended use.

Head the energy value of water, specified at a point, that is produced by the combined effects of elevation, pressure and velocity.

Heterogeneous aquifer an aquifer in a region of mixed geology where the hydraulic conductivity varies significantly across short distances.

Homogeneous aquifer an aquifer in a region of uniform geology where the hydraulic conductivity, in a specified direction, is constant throughout.

Hydraulic conductivity   (K), the rate at which a fluid can move through a permeable material.

Hydraulic gradient   the change in hydraulic head over a specified distance in a given direction.

Hydraulic head   the total head, the sum of the elevation and pressure heads (the head due to velocity is typically negligible).

Hydrogeology   the study of ground water and it's relationship to the geologic environment.

Hydrologic cycle   the continuous circulation of water between the ocean, atmosphere, and land (including the subsurface).

Infiltration   the process of water or other fluids seeping into the surface materials (see also percolation).

Influent stream   a stream which loses water to (recharges) the underlying ground water zone.

Impermeable layer   a formation of geologic material with a low hydraulic conductivity that allows little or no water to permeate through it.

Isotropic Aquifer   an aquifer in which the magnitude of the hydraulic conductivity is equal in all directions.

Leaching   the washing of chemicals and plant nutrients from the root zone by percolating water.

Mechanism   the fundamental process for an action.

Overdraft   the withdrawal of ground water at a rate greater than the rate of recharge; such practices lead to the eventual depletion of the resource.

Overland flow   initial flow of precipitation over the land surface toward a common collection area such as lake or stream.

Perched water table   a localized zone of ground water above the first aquifer caused by a confining layer of limited areal extent; usually can not produce significant amounts of water.

Percolation   to ooze, trickle, or move through a permeable substance

Permeability   the measurement of an aquifer's ability to transmit or yield water.

Piezometer   a small diameter open pipe which is used to measure the water table or potentiometric surface.

Porosity   the percentage of the total volume of material which is void space.

Potentiometric surface   the level to which water rises in a well. For an unconfined aquifer, its the water table.

Precipitation   the process of water vapor condensing out of the atmosphere and falling or otherwise being deposited onto the land surface.

Pressure Head   the pressure exerted by a column of water from the point of measurement to the top of the column.

Recharge   water movement into the saturated zone from the unsaturated zone or from a surface body of water. Confined aquifer recharge can occur through a leaky confining layer.

Residence time   the time needed for a water particle to travel through the aquifer from a point of recharge to a point of discharge.

Root zone   the uppermost segment of soil in the unsaturated zone that is populated with plant roots. This is the target zone for most soil amendments. Agricultural chemicals which leach below the root zone waste money and could potentially contaminate the ground water.

Runoff   concentrated surface water flow from a precipitation or irrigation event or snow melt that contributes to stream flow.

Saturated Zone   the area of soil or bedrock in which all void spaces are filled by water. Layers within the saturated zone that are capable of transmitting a usable quantity of water to a well are called aquifers. Note that even confining layers below the water table are saturated.

Soil moisture   water contained in the unsaturated zone.

Specific yield   the ratio of the volume of water that will drain under the influence of gravity to the volume of saturated rock.

Steady-state flow	a condition where the amount of discharge is equal to the amount of recharge and the ground water flow is constant.
Storage	the net amount of ground water in an aquifer at a specific point in time.
Stream flow	the down-slope movement of water in a surface stream, river, etc. resulting from runoff plus baseflow.
Transient flow	opposite of steady-state flow (unsteady flow), a condition where ground water flow changes with time due to an imbalance between recharge and discharge.
Transmissivity	the distance per day an aquifer can move a volume of water. The hydraulic conductivity times the height of the aquifer (K x b).
Transpiration	the process by which plants give off water vapor through their leaf surfaces.
Unconfined aquifer	The water table aquifer (also called the phreatic aquifer). A saturated zone capable of producing a useful amount of water with no overlying confining layer; ground water in this type of aquifer is maintained at atmospheric pressure through the empty pore spaces of the geologic material above it.
Unconsolidated	loosely packed subsurface materials exhibiting little or no cementation such as gravel, sand or clay.
Vadose zone	the section between the bottom of the root zone and the top of the saturated zone (i.e. the water table) in which the pore spaces are only partially filled with water.
Water table	the top surface of the unconfined saturated zone.
Well	an excavated hole, usually of small diameter in comparison with its depth, which penetrates an aquifer and provides a means for water to enter the hole while soil and rock material is excluded.
Well screen	a filtering device with either slots, holes, gauze, or continuous-wire wrap usually placed at the bottom end of the well casing. The water enters the well through the well screen which excludes the surrounding geologic materials.

Yield, well   the maximum rate a well can be pumped without lowering
                             the water level in it.

Yield, aquifer   the maximum rate at which an aquifer can be pumped
                             without reducing the hydraulic head to an unacceptable level.

Zone of contribution   the area around a well that contains the entire surface and
                             subsurface areas from which the pumping well receives water.

Zone of influence   the area around a pumping well that contains the entire cone
                             of depression from an unconfined aquifer.

Zone of transport   an assumed safe area around a well based on water transport
                             to the well given in years.

IX. GLOSSARY OF CONTAMINANT TRANSPORT TERMS

Advection (bulk flow)   soluble particle movement at the general rate of the water around them.

Concentration   the amount of pollutant in a specified volume of water by weight or percentage.

Density   the mass of a material divided by its volume.

Dilution time   the time needed to reduce the concentration of a pollutant in a water sample to some acceptable concentration by natural or forced aquifer movement.

Dispersion   soluble particle movement at a rate faster than the general rate of the water around them.

Inorganic chemical   compounds made of elemental components without a carbon base (e.g. nitrate).

Microbiological   small-scale living organism such as bacteria.

Organic chemical   compounds with a carbon base (e.g. oil).

Nonpoint source   a distributed pollutant source spread out in low concentrations over a large area.

Parts per billion   one gallon of a substance dissolved in one billion gallons of water. Abbreviated "ppb"; also given as micrograms per liter (ug/l). A one ppb concentration is the same relationship as one second of time out of 32 years. If you use creamer in your coffee, in order to make a 1 ppb concentration you would have to dissolve one teaspoonful of creamer in 1.3 million gallons of coffee. That's almost two Olympic-sized swimming pools filled with coffee.

Persistence   a measure of the time needed to reduce a pollutant concentration by 50%.

Point source   a concentrated, small-area pollutant source.

Root uptake   the natural transfer of water and soluble materials, such as fertilizer, through cells in the plant roots.

Solubility   a measure of how readily a material will dissolve in water.

Sorption   a microscopic mechanism in which chemical particles are attracted to clay particle surfaces.

Vapor Pressure   a measure of the tendency of a liquid to vaporize.

Viscosity   the property of a substance to offer internal resistance to flow.

Volatility   a measure of a material's ability to pass into the vapor phase under specified temperature and pressure.

X. MICHIGAN'S GROUND-WATER GEOGRAPHY - A REVIEW

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Bedrock Geology

Structure

North America, like all of the Earth's continents, is composed of three components: a shield, a stable platform, and folded mountain belts. The core of the continent is the craton which encompasses both the shield and the stable platform. The Canadian Shield is an area of highly deformed, metamorphic rocks and granitic intrusions of Precambrian age (see Table 5) which are exposed in the region between Hudson Bay and the upper Great Lakes. These are some of the oldest rocks in North America. To the south and southeast of the Superior province of the Canadian Shield, including all of Michigan, the igneous and metamorphic rocks of the basement complex change in composition and are progressively younger, although still Precambrian, in age. Beginning in the eastern Upper Peninsula and continuing southward, the basement complex is covered with a sequence of Paleozoic and younger sedimentary rocks. Although originally deposited nearly horizontally, in the Central Lowlands region these lithified sediments have been warped into broad, shallow domes and basins.

In the Great Lakes Region, there are several broad uplifts where Precambrian basement rocks occur at or near the surface (Figure 18). To the south of Michigan, there is the generally north-trending Cincinnati arch. Midway between the Ohio River and southernmost Michigan, this arch splits into two prongs along the Indiana-Ohio border. The northeastward trend, called the Findlay arch, continues through the western end of Lake Erie to eventually join the Canadian Shield in Ontario. The other prong of the Cincinnati arch, commonly known as the Kankakee arch, trends northwestward to join the north-trending Wisconsin arch in south-central Wisconsin. The Wisconsin arch merges with the Wisconsin dome which occupies the majority of the northern third of Wisconsin. The western half of the Upper Peninsula continues this positive trend in the form of the Superior Upland, an extension of the Canadian Shield.

Table 5. Geologic Time Scale.

millions of years before present	duration in millions of years	EPOCH	PERIOD	ERA
1.6	1.6	Pleistocene	Quaternary	
5.3	3.7	Pliocene		
23.7	18.4	Miocene		
36.6	12.9	Oligocene	Tertiary	Cenozoic
57.8	21.2	Eocene		
66.4	8.6	Paleocene		
144	78		Cretaceous	
208	64		Jurassic	Mesozoic
245	37		Triassic	
286	41		Permian	
320	34		Pennsylvanian	
360	40		Mississippian	
408	48		Devonian	Paleozoic
438	30		Silurian	
505	67		Ordovician	
570	65		Cambrian	
				Precambrian
4,600 ?		Formation of the Earth		

Major Basement Rock Structures

Wisconsin Dome

Wisconsin Arch

Michigan Basin

Findlay Arch

Kankakee Arch

Allegheny Basin

Illinois Basin

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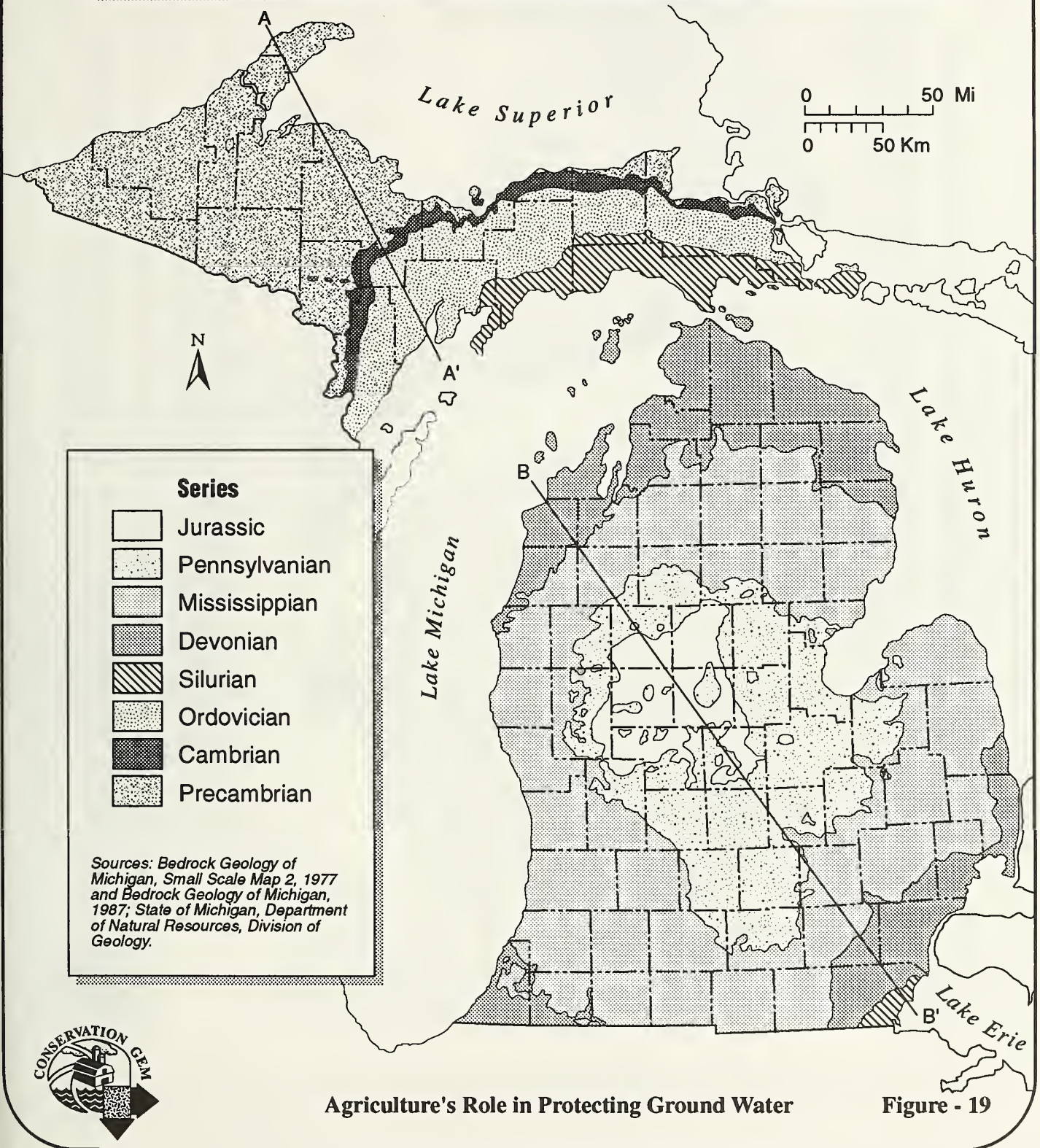
Figure - 18

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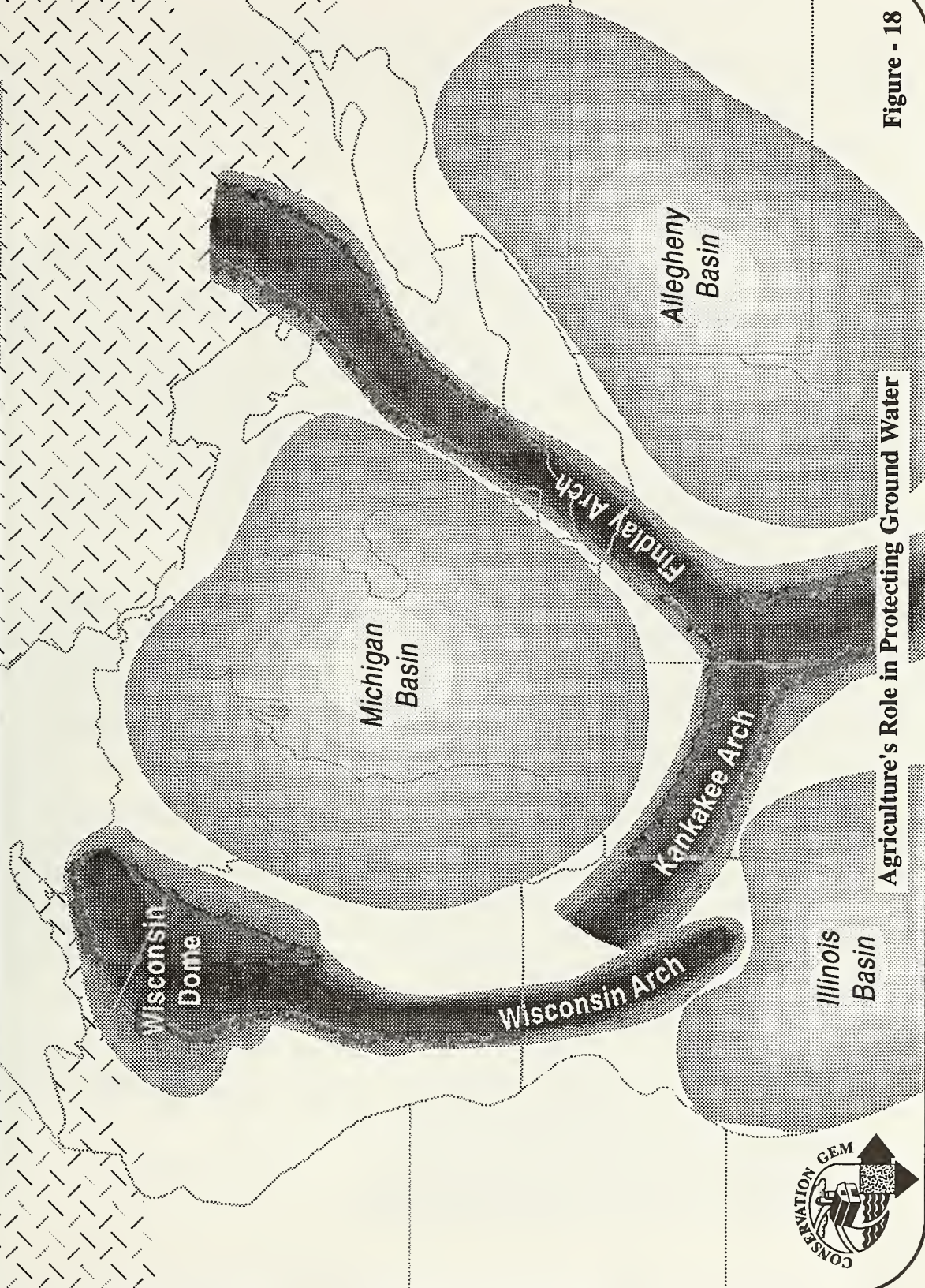
The Michigan Basin is the central negative structure in the Great Lakes Region. It is bounded on the north by the Canadian Shield, on the east by the Algonquin arch, on the south by the Kankakee and Findlay prongs, and on the west by the Wisconsin arch/dome and the Superior Upland. Two other structural basins also occur in this region of the continent. East of the Findlay arch is the Allegheny Basin. The Illinois Basin lies southwest of the Kankakee arch.

The Michigan Basin encompasses about 122,000 square miles and contains about 108,000 cubic miles of sedimentary rocks which filled a depression in the Precambrian basement complex. The vast majority of these sedimentary rocks are Paleozoic age although patches of late Jurassic rocks subcrop beneath the glacial drift in the west-central portion of the Lower Peninsula (Figure 19). The oldest sedimentary rock unit in Michigan is the Jacobsville Sandstone of late Precambrian age which is found along much of the north shore of the Upper Peninsula (Figure 20). The oldest Paleozoic sedimentary rocks (Cambrian) are found at or near the surface along the northern fringe of the eastern Upper Peninsula and arcing southward to the big bend in the Menominee River in southern Menominee County. The oldest sedimentary rocks in the Lower Peninsula, found in southeastern Monroe County, are Silurian in age.

The thickness of the sedimentary rocks increases from the margins toward the center of the basin which is located near the middle of the Lower Peninsula. A hydrocarbon exploration well drilled in North Star Township, Gratiot County penetrated more than two miles of sedimentary materials before entering the Precambrian basement complex. The concentric, ovoid pattern of the sedimentary rocks in Michigan, illustrated in Figure 19, is an indication of the basin's saucer-like structure.

An example of the margin of the sedimentary basin is shown in Figure 20. The Ordovician and Cambrian units of the sedimentary sequence can be seen to thin as they reach the erosional limits of the basin. The underlying Precambrian rocks which slope down into the basin can also be observed in this cross section. Figure 21 presents a section across the Lower Peninsula which passes near the center of the structural basin. The inclinations of the various sedimentary units on this graphic have been greatly exaggerated for clarity. Basin-wide, the average dip of the beds is less than one degree -- about 45-60 feet per mile. Such a declivity would appear to be horizontal if viewed in an outcrop. Given the size of the basin, however, this slight inclination is sufficient to account for the rocks that form the coastline of the eastern Upper Peninsula being found over 10,000 feet below the surface of the central portion of the Lower Peninsula.

Bedrock Geology of Michigan

Series
- Jurassic
- Pennsylvanian
- Mississippian
- Devonian
- Silurian
- Ordovician
- Cambrian
- Precambrian

Sources: Bedrock Geology of Michigan, Small Scale Map 2, 1977 and Bedrock Geology of Michigan, 1987; State of Michigan, Department of Natural Resources, Division of Geology.

Lake Superior

Lake Michigan

Lake Huron

Lake Erie

0   50 Mi

0   50 Km

N

Agriculture's Role in Protecting Ground Water

Figure - 19

Geologic Cross Section of the Upper Peninsula

Series

- Mississippian
- Devonian
- Silurian
- Ordovician
- Cambrian
- Precambrian
- Precambrian - Jacobsville Sandstone

Sources: Bedrock Geology of Michigan, Small Scale Map 2, 1977 and Bedrock Geology of Michigan, 1987; State of Michigan, Department of Natural Resources, Division of Geology.

N

Lake Superior

A Isle Royale

Lake Superior

Keweenaw Fault

Glacial Drift

Green Bay

A'

0   50 Mi

0   50 Km

Figure - 20

Agriculture's Role in Protecting Ground Water

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Geologic Cross Section of the Lower Peninsula

Series

▢ Jurassic	▨ Silurian		
▨ Pennsylvanian	▨ Ordovician		
▨ Mississippian	▰ Cambrian		
▨ Devonian	▨ Precambrian		

Sources: Bedrock Geology of Michigan, Small Scale Map 2, 1977 and Bedrock Geology of Michigan, 1987; State of Michigan, Department of Natural Resources, Division of Geology.
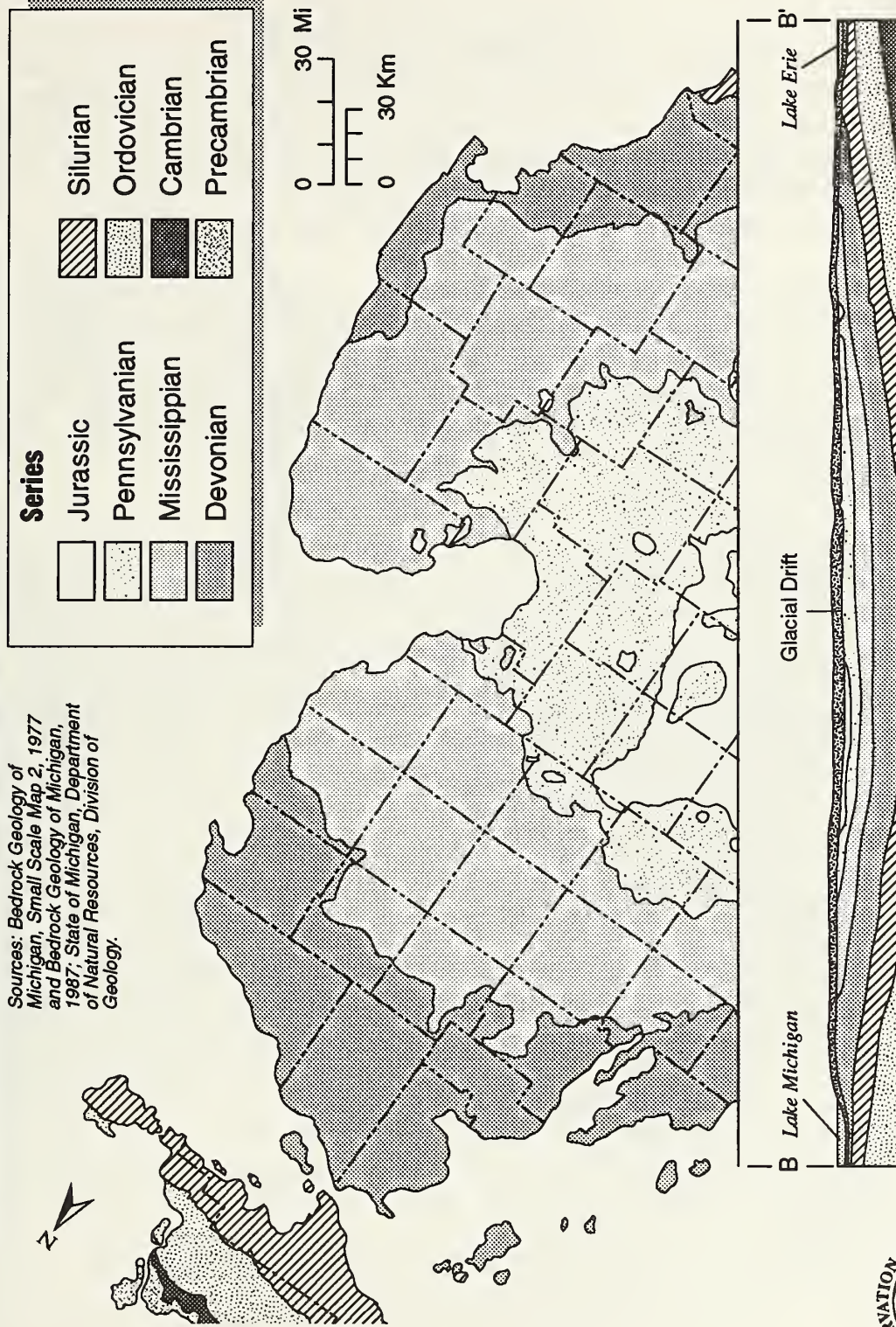
N

0   30 Mi

0   30 Km

B

Lake Michigan

Glacial Drift

Lake Erie

B'

Agriculture's Role in Protecting Ground Water

Figure - 21

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Lithology

As mentioned previously, the majority of the Precambrian basement complex is composed of crystalline rocks (i.e. igneous and metamorphic). An exception to this is the Precambrian Jacobsville sandstone, shown in part in Figure 20. Of the Paleozoic and Jurassic sedimentary rocks which fill the basin, about 47 percent of them are carbonates (i.e. limestone or dolostone), 23 percent are sandstones, 18 percent are shales, and roughly 12 percent are evaporites (i.e. salt, anhydrite, and gypsum).

Most of the sedimentary rocks in the Michigan Basin originated as marine deposits. Near-shore areas in these ancient seas received sandy sediments which became sandstone when lithified. In somewhat deeper waters, fine-grained muds were deposited -- the source for our shales. In the deepest parts of these oceans, calcareous-rich sediments were deposited which through geologic time became limestone or dolostone. Special lagoonal environments under conditions of high evaporation rates account for the salt, anhydrite and gypsum deposits.
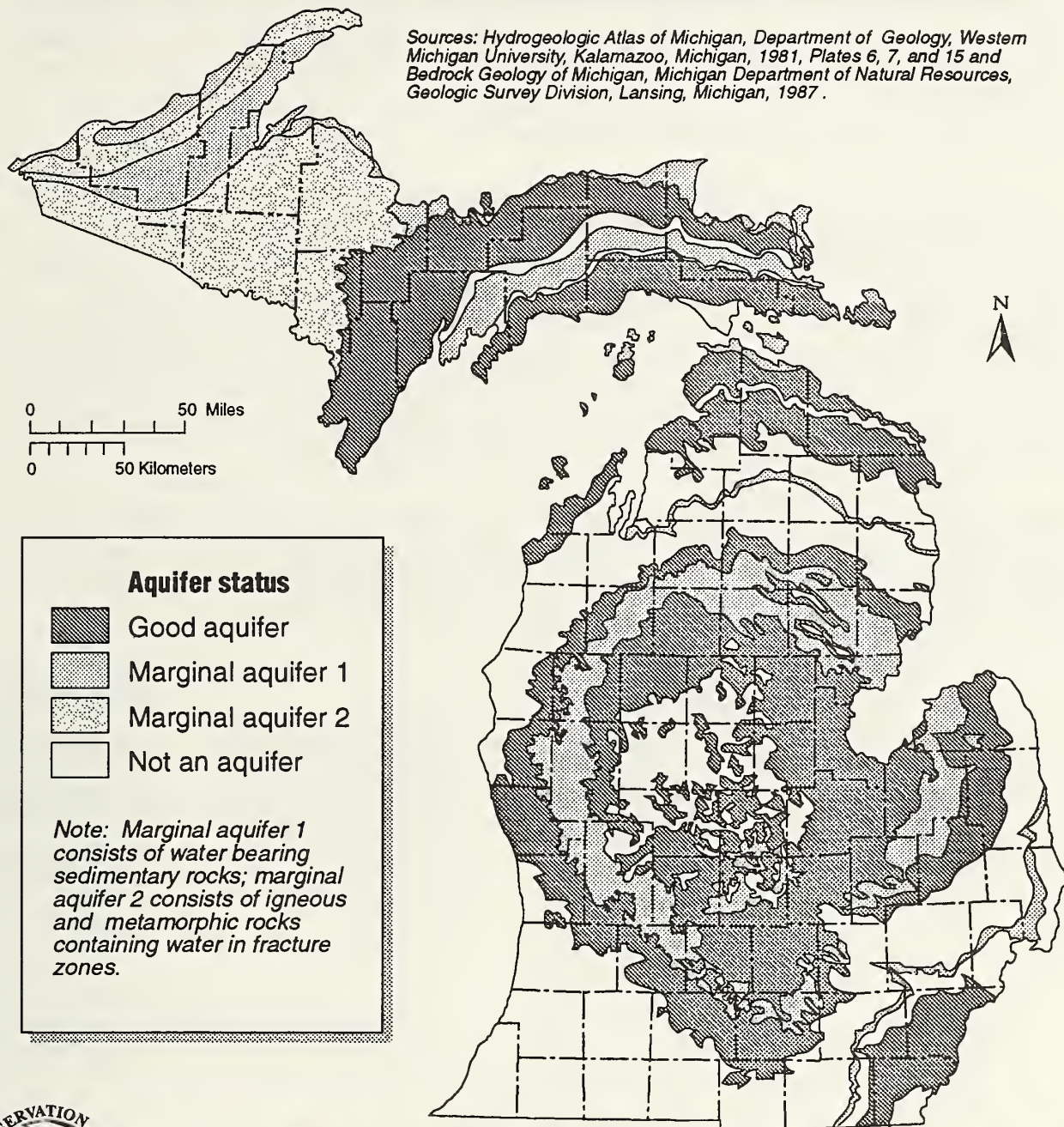
Most of the Ordovician, Silurian and Devonian Periods in Michigan's stratigraphic record are dominated by the carbonate rock types. Various grades of sandstone dominate much of the Cambrian Period and smaller portions of the Middle Ordovician, Late Silurian, Early Devonian, Early Mississippian and Late Pennsylvanian Epochs. Shales dominate much of the Mississippian Period and short intervals of the Late Ordovician, Early and Late Silurian, Late Devonian, and Early Pennsylvanian Epochs. The evaporites are confined largely to the Middle and Late Silurian and Middle Devonian Epochs.

Bedrock Aquifers

The availability of potable ground water in bedrock units is controlled, in part, by the porosity of the rock -- the ratio of the volume of openings in the rock to the total volume of the unit. We differentiate between two different types of voids in rocks. Primary porosity refers to openings that were formed at the same time as the rock. The pore spaces between the grains of sand in a sandstone are an example. If the voids were formed after the material was lithified, they are termed secondary porosity. Examples of these secondary openings are fractures in a crystalline rock or solution openings in a limestone. The hydraulic conductivity of a rock expresses its capacity to transmit water. The size and interconnections of the primary and secondary openings largely control this parameter. In Michigan, as elsewhere, the porosity and hydraulic conductivity of the different bedrock units vary considerably. Another factor to consider is that much of the saturated thickness of the bedrock in Michigan contains non-potable brine. Figure 22 illustrates the pattern and extent of the major bedrock aquifers of Michigan.

Bedrock Aquifers

N

0   50 Miles

0   50 Kilometers

Aquifer status

Good aquifer

Marginal aquifer 1

Marginal aquifer 2

Not an aquifer

Note: Marginal aquifer 1 consists of water bearing sedimentary rocks; marginal aquifer 2 consists of igneous and metamorphic rocks containing water in fracture zones.

CONSERVATION GEM

Agriculture's Role in Protecting Ground Water   **Figure - 22**
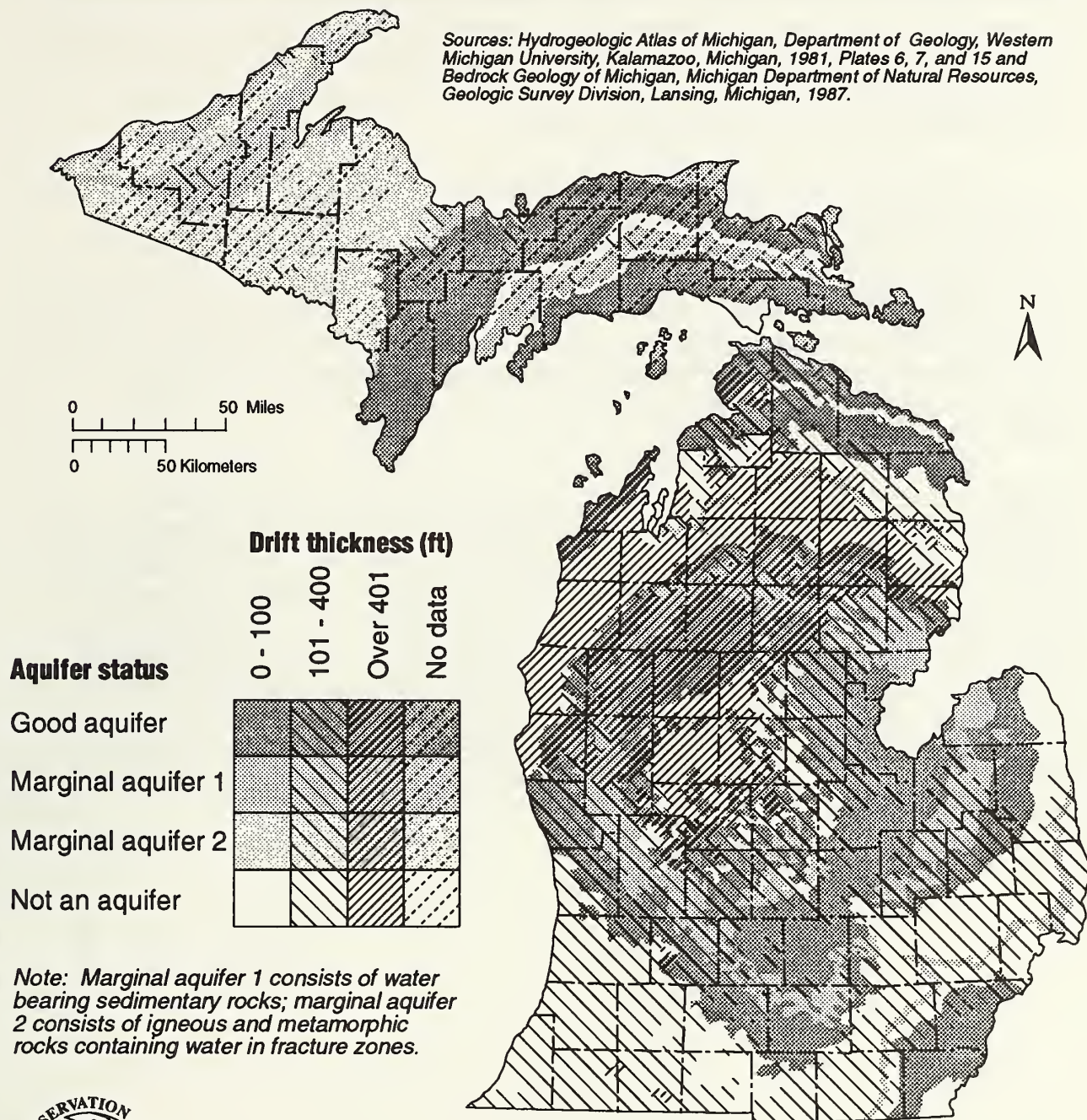
63

Figure 23 shows the accessibility of the bedrock aquifers in terms of the thickness of the glacial materials which bury them in most places. The good aquifers shown on this map routinely provide potable ground water of adequate quantity and quality. The marginal aquifers are those which provide low-quality water and/or have highly variable transmissivities (i.e. notable changes in hydraulic conductivity and/or aquifer thickness from place to place). The marginal 1 class consists of saturated, sedimentary rock units. The marginal 2 class represents the igneous and metamorphic rock types in the western Upper Peninsula which have little or no primary porosity; in these hard rock areas, ground water is found only in joint and fracture zones.

Bedrock aquifers are frequently tapped for domestic water supplies in areas where they are overlain by relatively thin (0-100 feet) drift. Examples include the Keweenaw Lowland in the western Upper Peninsula, many areas of the eastern Upper Peninsula, the vicinity of Presque Isle County in the northeastern Lower Peninsula, the tip of Michigan's "thumb", the area around Monroe County in southeasternmost Michigan, and a swath of variable width extending southwestward from Saginaw Bay to the state line in Branch and Hillsdale counties. In contrast, the bedrock aquifers below the northwestern and north-central regions of the Lower Peninsula are typically buried beneath more than 400 feet of glacial drift and are, therefore, not generally accessible.

Many parts of the Lower Peninsula have little or no potable ground water in the underlying bedrock, making these locales dependent on drift aquifers or surface water supplies. The most notable of these areas are the entire southwestern region and a county-wide zone that traverses the southeastern sector of the state.

Accessibility of Bedrock Aquifers

0   50 Miles

0   50 Kilometers

N

Drift thickness (ft)

0 - 100
101 - 400
Over 401
No data

Aquifer status

Good aquifer

Marginal aquifer 1

Marginal aquifer 2

Not an aquifer

Note: Marginal aquifer 1 consists of water bearing sedimentary rocks; marginal aquifer 2 consists of igneous and metamorphic rocks containing water in fracture zones.

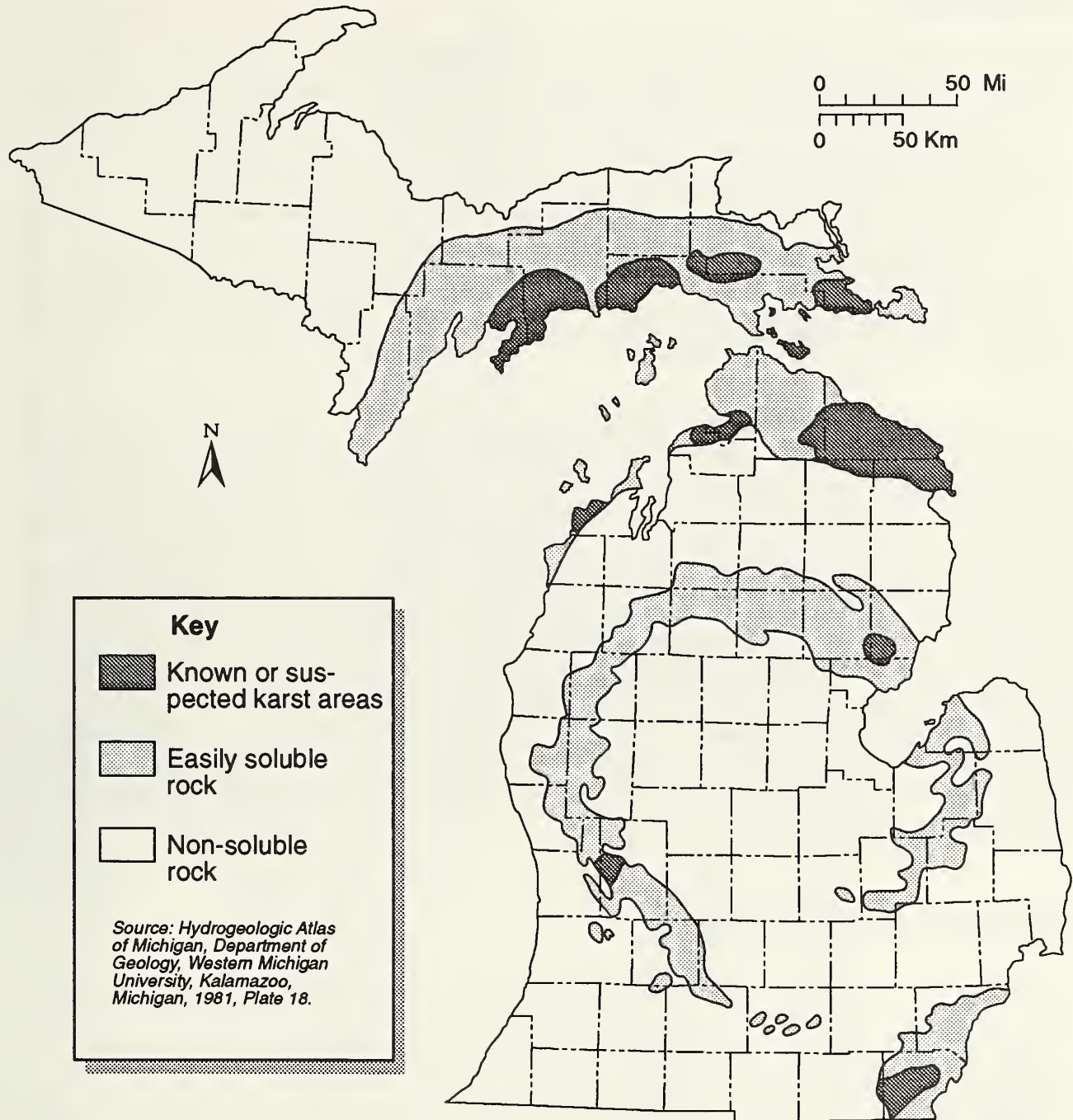**Agriculture's Role in Protecting Ground Water**   **Figure - 23**

Areas of Special Concern

Within the Michigan Basin, there are numerous strata of carbonate rocks. These limestones and dolostones can be dissolved by water. In areas where the carbonate rocks are highly fractured, numerous solution-widened joints develop. These may extend underground for long distances. Progressive solution leads to the development of small cavities and larger caves and caverns. As subterranean solution continues, some of these solution features can collapse causing subsidence of the overburden. A landscape exhibiting these landforms is called karst terrain.

The various solution features associated with karst regions provide numerous pathways for surface contaminants to infiltrate very rapidly into the subsurface. The rates of ground-water flow in these systems can approach those of some surface streams. Even more disturbing, the subterranean interconnections between these solution voids are generally unknown and unpredictable. As a result, hazardous materials which move into the ground water in a karst region can travel very rapidly to wells located great distances from the contamination site. These conditions make the karst areas of Michigan particularly vulnerable to potential contamination from human activities at or near the surface.

The darkest pattern in Figure 24 depicts the known or suspected areas of karst in Michigan. The lighter-gray pattern delineates regions of easily soluble rock types where similar underground solution features are possible. In areas where these lithologies are near the surface, subterranean karst development is probable. Notably, the karst areas along the south shore of the Upper Peninsula, in the general vicinity of Presque Isle County in northeastern Lower Michigan, and in Monroe County in southeasternmost Michigan are all overlain by relatively thin amounts of drift -- usually less than 50 feet thick. Hence, there is minimal opportunity for the overburden to attenuate any percolating contaminants from the surface. Everyone who lives, works or recreates in these parts of the state needs to be especially conscious of and careful with hazardous substances.

Karst Areas in Michigan

0 ——— 50 Mi

0 ——— 50 Km

N

Key

Known or sus-
pected karst areas

Easily soluble
rock

Non-soluble
rock

Source: Hydrogeologic Atlas
of Michigan, Department of
Geology, Western Michigan
University, Kalamazoo,
Michigan, 1981, Plate 18.

CONSERVATION GEM

Agriculture's Role in Protecting Ground Water

Figure - 24
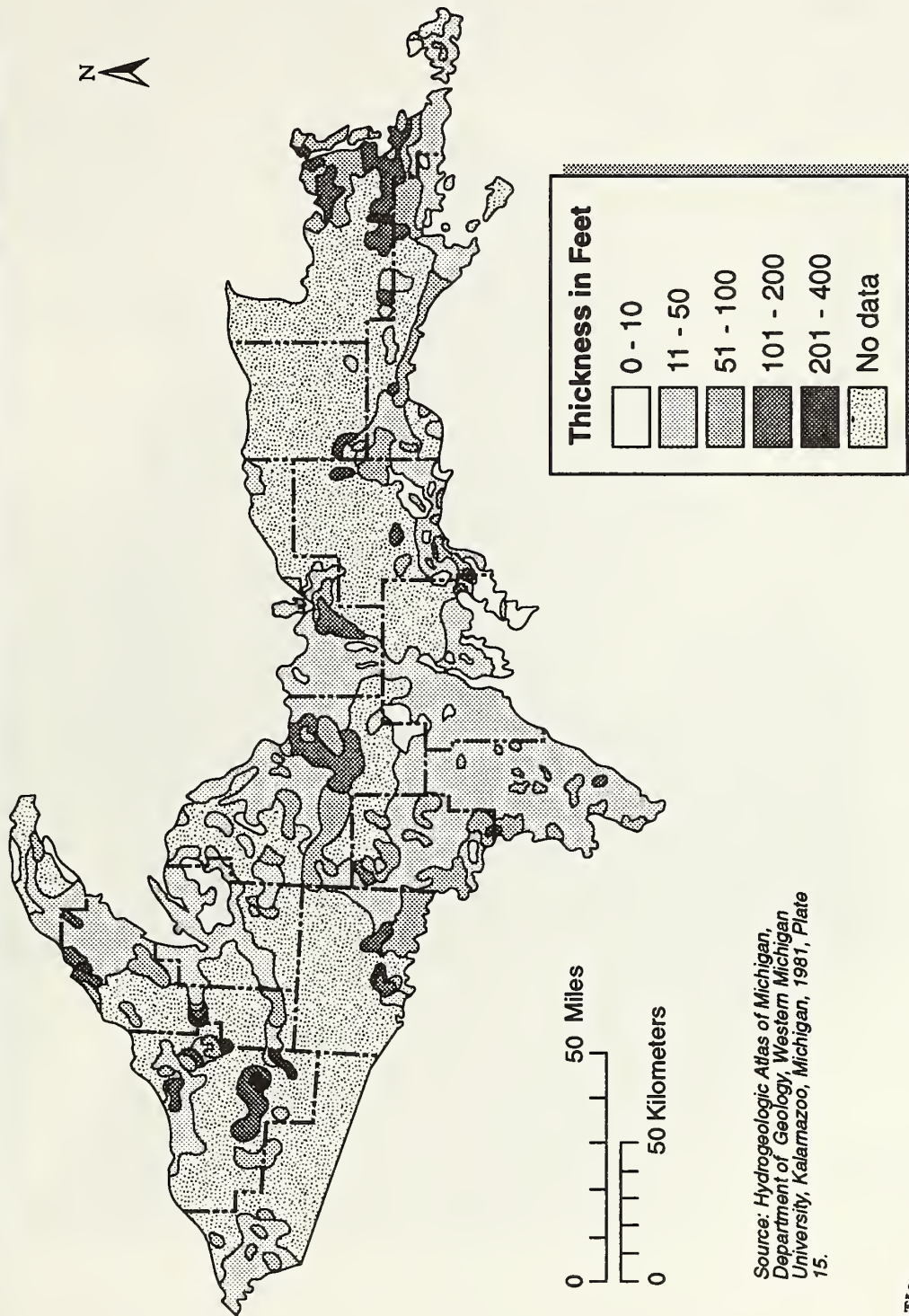
Glacial Geology

Introduction

During the last ice age, all of Michigan and the bordering Great Lakes basins were engulfed by the Laurentide ice sheet. This continental glacier advanced into an area that had been glaciated at least three times previously in the recent geologic past. The initial invasion of Pleistocene glaciers probably encountered a rolling countryside that had been maturely dissected by flowing streams. This landscape was underlain by nearly horizontal sedimentary rock layers which possess varying resistances to erosion. The downcutting of streams is more successful in the weaker rock units and less successful in the more resistant strata. As a result of this differential erosion, geomorphologists envision that the pre-glacial Great Lakes Region contained several master streams which flowed, primarily to the east and north, across the terrain now occupied by the lake basins.

The advancing ice was capable of enhanced flow in these pre-existing valleys compared to the interfluves. As a result, the ice front was dissected into a number of individual lobes with adjoining interlobate areas. Each of the lobes followed the local path of least resistance. The Superior Lobe flowed southwest in the western Lake Superior basin past Duluth. The Chippewa Lobe moved southwestward out of Keweenaw Bay across the lowland between the Keweenaw-Ontonagon ridges on the west and the Huron Mountains on the east. The Green Bay Lobe, which advanced toward the south-southwest, was separated from the neighboring Michigan Lobe by the resistant backbone of Wisconsin's Door Peninsula. The Michigan Lobe, the most robust of the seven discussed here, expanded primarily to the south. The Huron Lobe, flowing southeastward and then southward, was separated from the Saginaw Lobe by the low, resistant bedrock cuesta that forms the axis of Michigan's thumb. Entering the state from the east-northeast, the Erie Lobe merged with the Huron Lobe in the vicinity of Detroit and advanced as far as southeastern Branch County.

Drift Types and Thicknesses

The glaciers left most of Michigan buried in a variety of unconsolidated materials -- clay, silt, sand, gravel, and mixtures -- which collectively are called drift. The thickness of the drift varies considerably across the state and is a principal factor in the economical availability of ground water in bedrock aquifers. Also, the thicker the glacial materials are, the more likely it is that multiple drift aquifers will occur at depth. Figure 25 depicts the drift thicknesses in the Upper Peninsula. Large areas of "no data" are shown due to the small number of water wells in this part of Michigan. Where data are available, drift thicknesses less than 100 feet are common.

Drift Thickness in Upper Michigan

N

Thickness in Feet

- 0 - 10
- 11 - 50
- 51 - 100
- 101 - 200
- 201 - 400
- No data

50 Miles

0

50 Kilometers

0

Source: Hydrogeologic Atlas of Michigan, Department of Geology, Western Michigan University, Kalamazoo, Michigan, 1981, Plate 15.

Agriculture's Role in Protecting Ground Water

Figure - 25

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The picture is very different in the Lower Peninsula (Figure 26). Here, many parts of the northern half of the peninsula are deeply buried beneath 400 to 600 feet of drift. Many townships in Wexford, Osceola, and Otsego counties exhibit drift thicknesses in excess of 800 feet. This is in marked contrast to the very thin (less than ten feet!) drift in Presque Isle and Alpena counties. In the southern half of the Lower Peninsula, the drift is generally less than 400 feet thick. In this part of the state, the drift is thickest (200-400 feet) in the interlobate regions which trend from Cass County to northern Kent County in the southwest and, in the southeast, from Hillsdale County to southern Lapeer County. The tip of the thumb in Huron County, as well as most of Monroe County in the southeastern corner of the state, exhibit drift thicknesses of 50 feet or less. A two-county-wide zone of somewhat thin but variable drift thickness (generally less than 100 feet thick) trends southwestward from Saginaw Bay to Branch County.
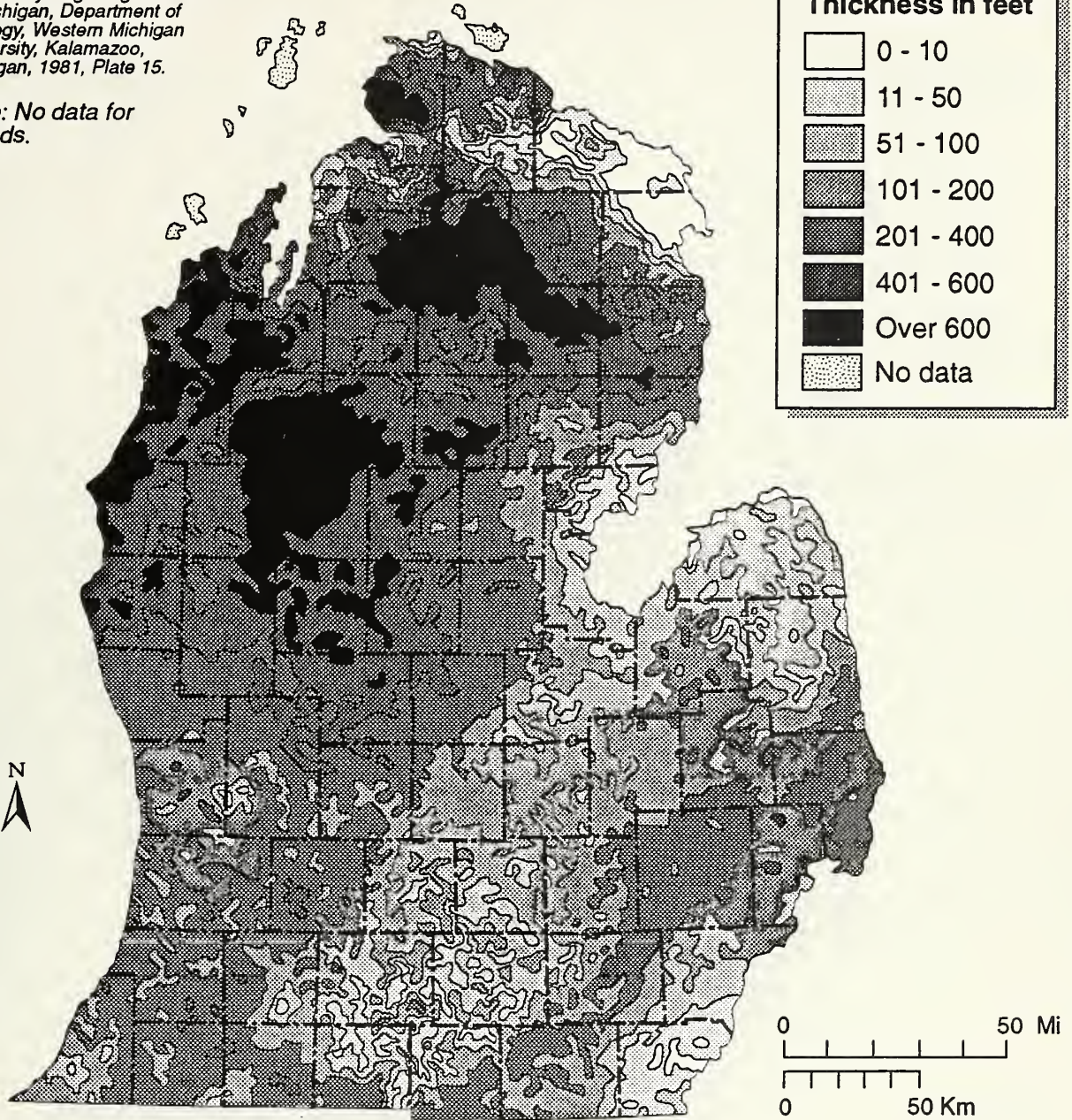
Drift Aquifers

On a statewide basis, ground water in drift aquifers is a plentiful resource as indicated by Figure 27. Most of the state is covered with glacial deposits which store and transmit ground water in amounts and rates that could meet the requirements of a small domestic supply system. Of course, this is a great generalization and on a local basis drift aquifers may be rare. The light-toned areas on Figure 27 depict regions of the state where one or more of the glacial Great Lakes inundated the present upland surface and deposited clay-rich materials. These lake plains are low-relief surfaces underlain by dominantly fine-textured drift which exhibits very low hydraulic conductivities. As a result, drift wells are not routinely possible in these sections of the state. The dark-tone pattern on Figure 27 reveals the distribution of areas underlain by 30 feet or less of glacial deposits. The well construction code in Michigan specifies that all water supply wells must be cased to a depth of 25 feet. Considering the need for several feet of screen at the bottom of a well in unconsolidated material, these thin-drift regions of the state provide very little opportunity to develop wells which could meet this construction standard.

Drift Thickness for Lower Michigan

Thickness in feet

	0 - 10
	11 - 50
	51 - 100
	101 - 200
	201 - 400
	401 - 600
	Over 600
	No data

N

0   50 Mi

0   50 Km

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Agriculture's Role in Protecting Ground Water

Figure - 26

Drift Thickness for Lower Michigan

Note: No data for islands.

Thickness in feet

- 0 - 10
- 11 - 50
- 51 - 100
- 101 - 200
- 201 - 400
- 401 - 600
- Over 600
- No data

N

0 — 50 Mi

0 — 50 Km

CONSERVATION GEM
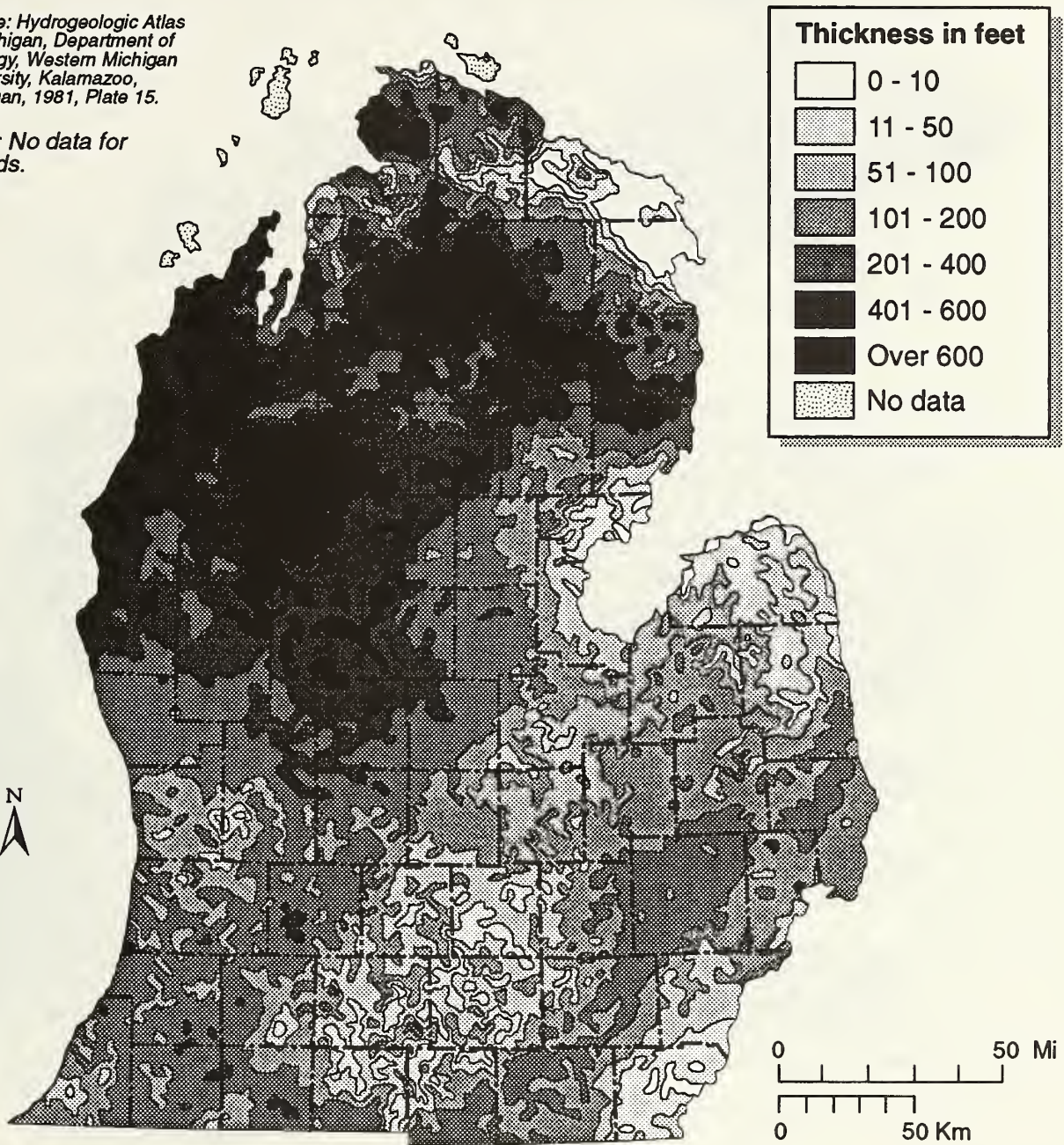
Agriculture's Role in Protecting Ground Water

Figure - 26

Drift Aquifers in Michigan

Key

Thin Drift
(0 - 30 feet)

Drift aquifer

Drift generally
NOT an aquifer

Source: Hydrogeologic Atlas of Michigan, Department of Geology, Western Michigan University, Kalamazoo, Michigan, 1981, Plate 26.
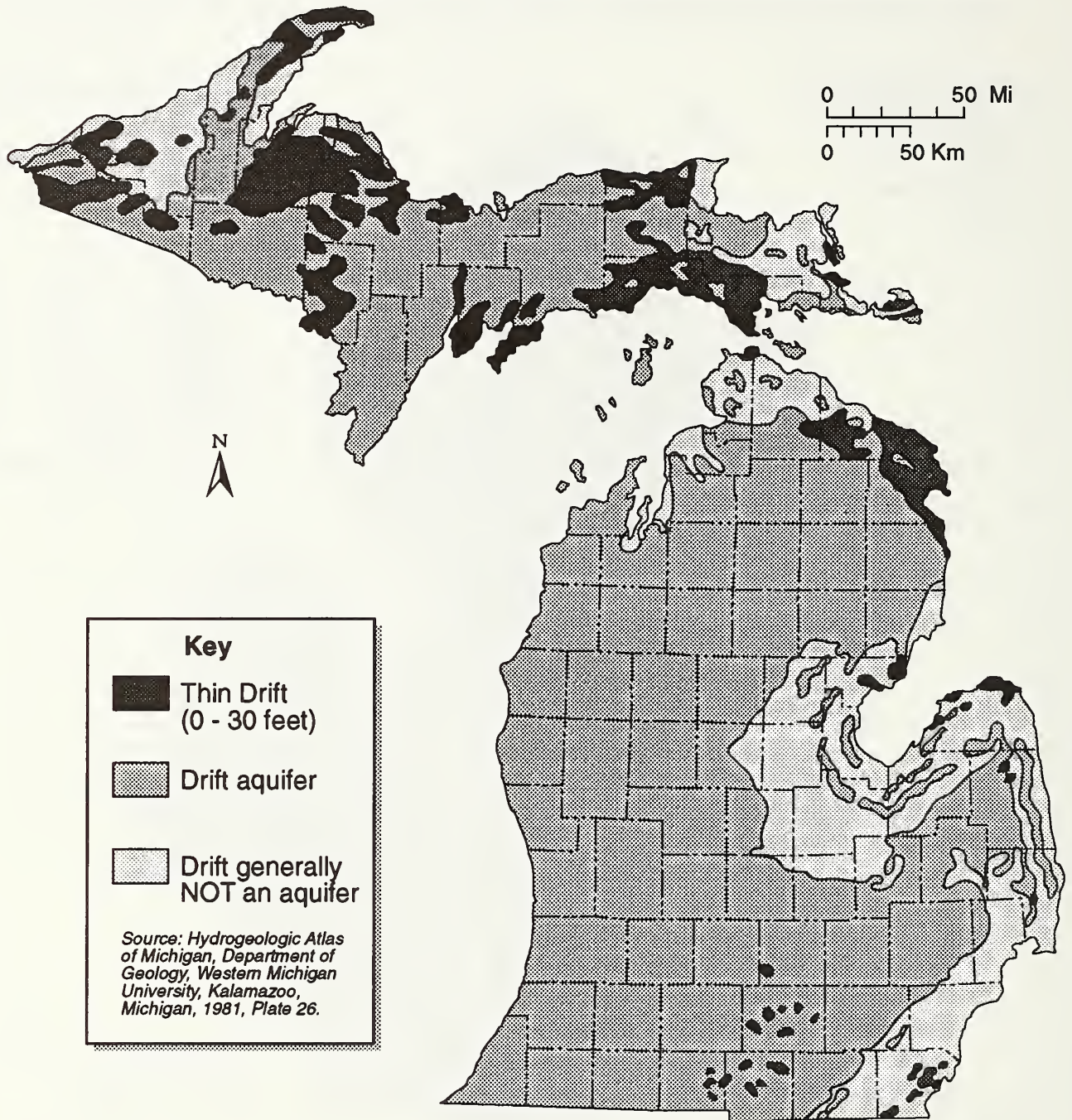
0   50 Mi
0   50 Km

N

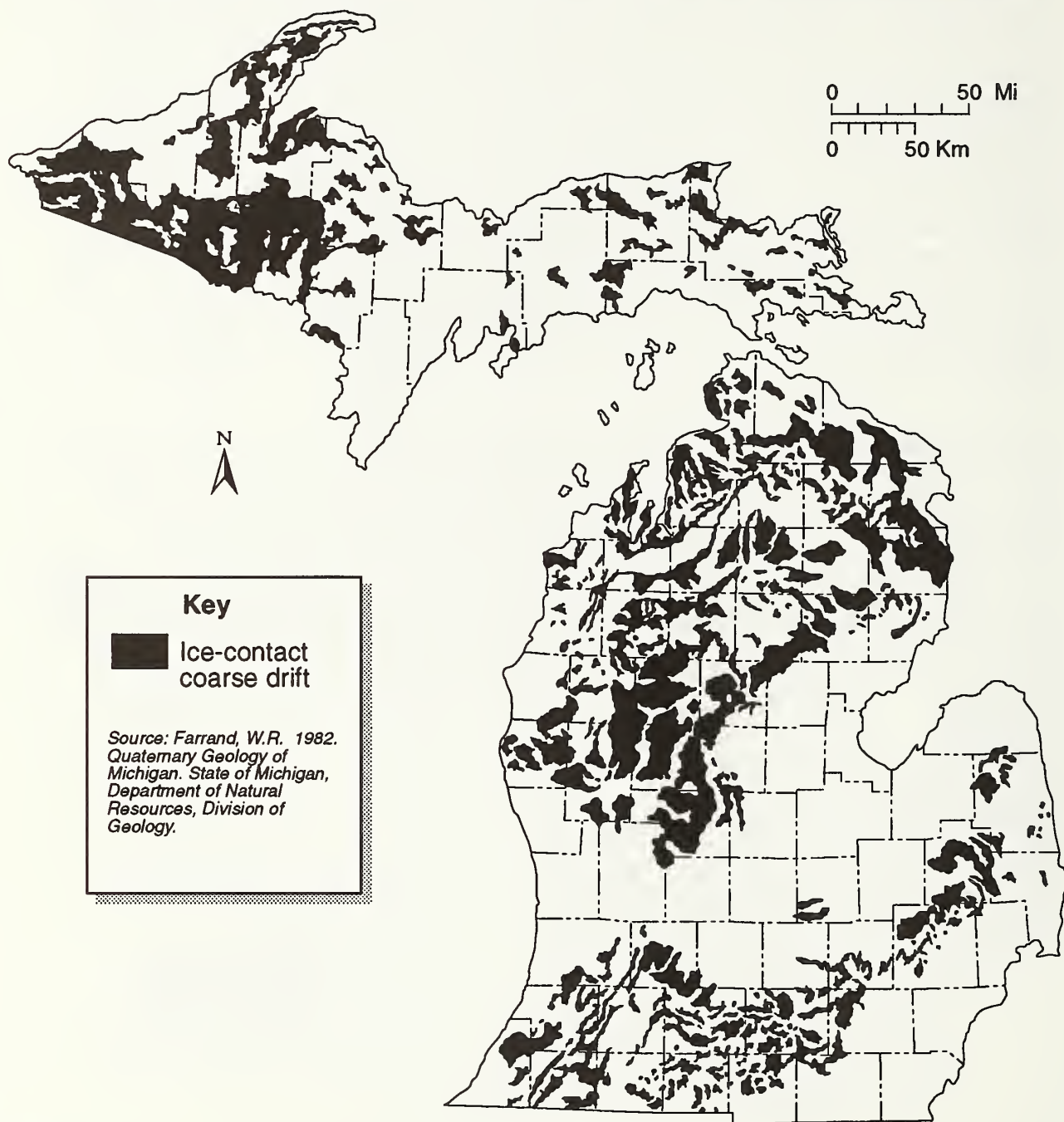**Agriculture's Role in Protecting Ground Water**   **Figure - 27**

Areas of Special Concern

We have seen that most of Michigan is covered with glacial deposits. From a statewide perspective, bedrock exposed at the surface is relatively rare. This implies that the water table (the upper surface of the ground water) is most often found in the drift. The vulnerability of ground water to contamination from the surface or near surface (i.e. human activities) is controlled primarily by the hydraulic conductivity of the materials through which infiltration occurs and the thickness of the unsaturated zone. Highly permeable soils allow surface contaminants to migrate rapidly into the subsurface. Less porous soils, on the other hand, inhibit the infiltration of contaminants. The depth to the water table (i.e. the thickness of the unsaturated zone) is a measure of the vertical distance that contaminants must travel in order to reach ground water. The elevation of the water table is a function of surface topography and the altitude of the local ground-water discharge zones. In general, the configuration of the water table mimics the form of the surface, but with much less local relief. For certain types of chemicals, the amount of organic matter in the soil modulates how effectively it can attenuate the potential contaminant.

Considering these factors, the ice-contact, coarse-drift terrains, shown in Figure 28, are some of the most vulnerable landscapes in Michigan. They are composed of highly porous soils which contain relatively little organic matter. Compared to proglacial outwash formations which are also composed of coarse material, the ice-contact landforms present a much higher degree of subsurface heterogeneity. They are typically underlain by a complex interfingering of varying textures which makes the ground-water flow regime very complicated. This combination of inherent vulnerability coupled with subsurface, three-dimensional complexity produces landscapes which are particularly challenging in terms of ground-water protection strategies.

Ice-Contact Coarse Drift

0 _____ 50 Mi

0 _____ 50 Km

N

Key

Ice-contact
coarse drift

*Source: Farrand, W.R. 1982.
Quaternary Geology of
Michigan. State of Michigan,
Department of Natural
Resources, Division of
Geology.*

CONSERVATION GEM

Agriculture's Role in Protecting Ground Water   **Figure - 28**

Naturally "Protected" Drift Aquifers

It is a well known fact that fine-textured earth materials transmit water very slowly compared to coarse soils. In Michigan, this concept is codified in the Rules of the Solid Waste Management Act (Act 641, P.A. 1978, as amended). As a means of safeguarding ground-water quality, these rules specify that a Type II sanitary landfill on a natural soil site should optimally be underlain by materials having a hydraulic conductivity no greater than 10^{-7} cm/sec. If the soil is thick enough, a hydraulic conductivity up to 10^{-6} cm/sec may be sufficient. These very low hydraulic conductivities are associated with clay soils.

Lakes and other still-water bodies are the environments in which clays can be deposited. Most lakes in Michigan are kettle lakes -- they occupy depressions which were formed when blocks of glacier ice finally melted after being partly or wholly covered by outwash sediments. Although some of these kettle depressions are very large, most are relatively small in size. In addition, since the littoral zone near the shore of a lake is the depositional site of coarse-textured material, it is only in the central portions of the lake that conditions are right for the deposition of clay. These facts suggest that most clay deposits will be local rather than regional in size. An inspection of the soil surveys of counties where clay-rich parent materials occur in abundance bears this conclusion out. Most soil map units that represent clay materials are 300 acres or less in size. Some larger areas of clay, up to 2,000 or 3,000 acres, do occur, but these are rare.

As depicted in Figure 29, the most common occurrence of clay materials in the drift of Michigan will be as discontinuous masses of relatively local extent, usually much less than 640 acres. As a result, the common assumption that extensive layers of clayey drift exist and provide natural protection to the confined aquifers at depth is largely incorrect. The infiltration pathway in the local area on the front left of Figure 29 is much slower than the pathway on the far right. However, recharge water (and any contaminants it carries) will infiltrate to the ground water system everywhere in the diagram. From this perspective, what some would call protection is really only an impediment to contaminant movement, not a barrier.
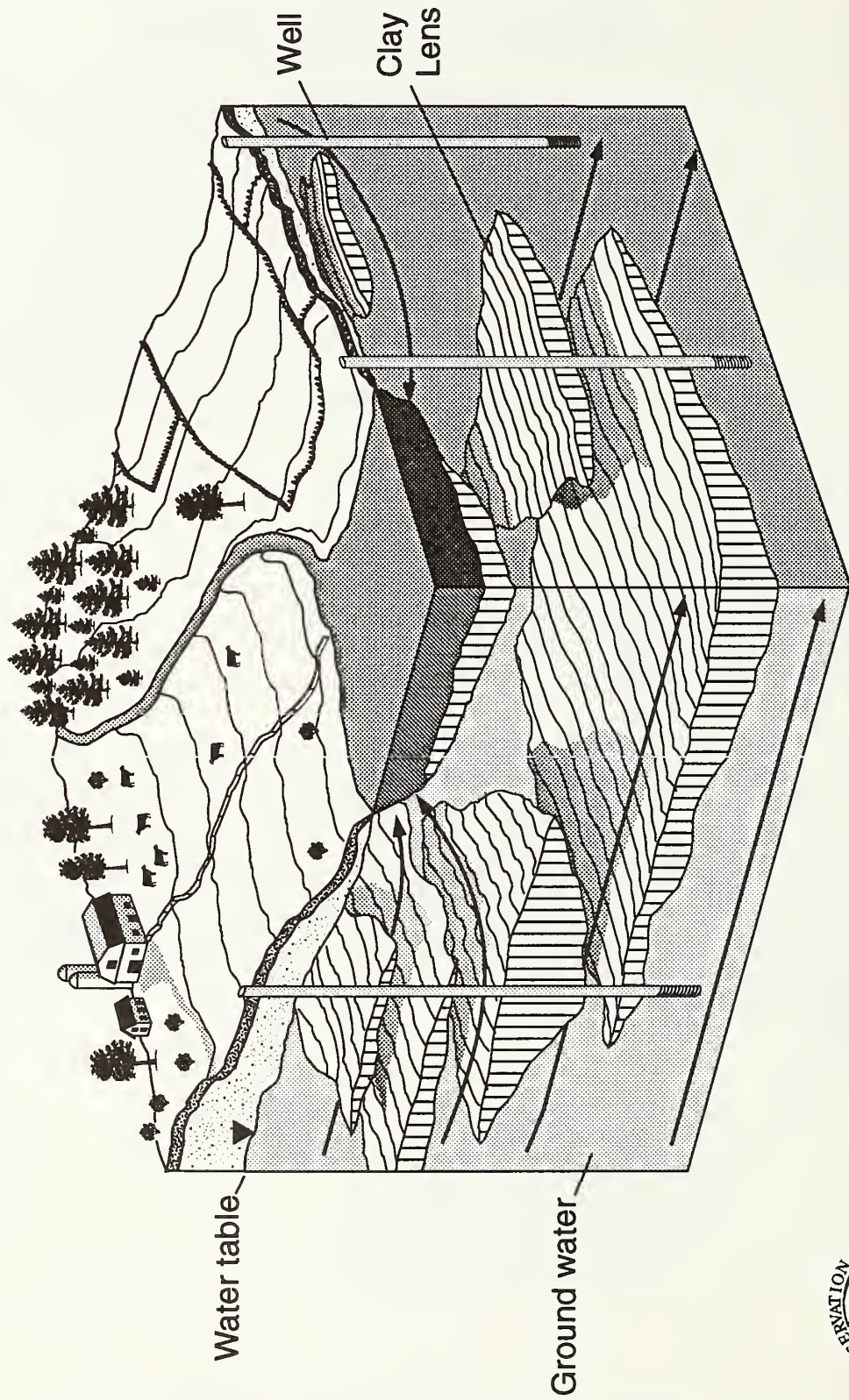
Discontinuous Confining Layers

Well

Clay Lens

Water table

Ground water

Figure - 29

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